# ECONOMIC GEOLOGY

AND THE

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# ECONOMIC GEOLOGY

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VOL. 49 AUGUST, 1954 NO. 5


## THE ORE DEPOSITS OF JUGOSLAVIA AND THE DEVELOPMENT OF ITS MINING INDUSTRY


FRIEDRICH SCHUMACHER [1]


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ABSTRACT

This paper is the first comprehensive description of the mineral deposits of Jugoslavia. It is based on present conditions and is the result of the author's residence in that country from 1947 to 1951.

Geologically, most of the Jugoslavian mineral deposits belong to a metallogenetic epoch associated with Tertiary volcanism as they are spatially and genetically related to the eruption of andesitic, dacitic, and trachytic rocks. Others are part of a serpentine province characterized by numerous occurrences of chromite and magnesite. To a lesser extent, deposits of asbestos are found in this group. Between these two distinct types are various deposits of magmatic origin, but of otherwise uncertain geologic position. The sedimentary cycle is represented by marine iron and manganese deposits, as well as residual bauxite occurrences.

The deposits of magmatic derivation may be divided into three metallographic provinces as shown on the magmatic-tectonic map prepared by K. Stier. The *Wardar Zone* is the most important one owing to the abundance of lead-zinc, antimony, arsenic, and molybdenum occurrences; the *East Serbian* metallographic province contains large copper deposits; and the *Bosnian* province is mineralized with complex copper, quicksilver, gold, antimony, arsenic, and iron ores. The two provinces first named show definite relationships to Tertiary igneous activity; the geological position of the third has not as yet been clarified.

The major portion of this paper is devoted to descriptions of individual ore deposits or mineralized regions, many of which are of great economic importance. Among the latter are *Trepča*, the largest lead-zinc mine in Europe; *Bor*, the greatest European copper deposit; and the recently discovered copper deposit of *Majdan Pek*, which is destined to become a rival of Bor in its copper output.

Of importance for export are the antimony occurrences, the quicksilver mine of Idria, the chromite deposits of southern Serbia and Macedonia, as well as bauxite deposits, which are abundant in the Karst region along the Adriatic coast line from Istria to Montenegro.

## INTRODUCTION

THE present State of Jugoslavia has an area of 249,000 square kilometers and in 1950 had a population of more than 16 million people. It is a federated state which unites six autonomous peoples' republics, namely Serbia, Croatia, Slovenia, Bosnia, Herzegovina, Macedonia, and Montenegro, and accordingly is not nationally homogeneous. In the 1948 census, 87 percent of the population was classified as Jugoslavs, who again were divided into 65 percent Serbo-Croats speaking a unified language, 9 percent Slovenes, 5 percent Macedonians, 5 percent Mohammedans, and not quite 3 percent Montenegrins. The remaining 13 percent of the population, amounting to two million people, is made up of numerous minorities. The largest groups of these are the Albanians (three-quarters of a million) and the Hungarians (half a million). The German minority, formerly of considerable strength, has dwindled to insignificant size.

The Five-Year Plan, comprising the years 1947 to 1951, has emphasized the mining and electric power industries.

Three technical universities at Beograd, Zagreb, and Ljubljana supply the demand for engineers, chemists, etc. Mining faculties exist at Ljubljana, as well as at Zagreb and Beograd. After the war, a geological department was created at Beograd to serve the needs of the mining industry.

## THE MINING INDUSTRY BEFORE AND AFTER THE SECOND WORLD WAR

Mining in Jugoslavia is a very old industry. At some places, for instance the copper mines of Majdan Pek, it reaches back to prehistoric time as evidenced by the finding of stone-age tools. At many localities, the Romans have mined copper, argentiferous galena, and gold, although not all of the old mining activity dates back to Roman times. At Zlatica near Zletovo, Macedonia, Roman sculptures were found in a well preserved adit which had been driven by hand, probably for the recovery of gold-bearing copper ore.

Ancient mining operations flourished mainly during the late Middle Ages between the twelfth and sixteenth centuries; numerous dumps and caved workings date from this period, particularly in Serbia and Macedonia. The Trepča area is literally honeycombed with them. Slag dumps and the remains of smelters are also seen at many places. The mining operations of that period stem back principally to the so-called "Saxons," who were miners from the Erzgebirge and Harz Mountain districts. They emigrated to the Balkan countries and helped to develop the mining industry there to a flourishing degree. In the course of reopening some of the old mines, it was found that their workings penetrated to depths exceeding 200 meters. Argentiferous galena was the principal ore sought in those times.

After the invasion of the Turks, who in 1389 defeated the Serbs in the decisive battle of "Field of the Blackbirds," mining operations began to diminish and ceased entirely during the seventh century.

Modern development of the mining industry began after the First World War, assisted by the search for ores which Germany and Austria had carried on during the war.

The founding of the "Trepča Mines Limited" in 1927 gave a particularly strong impetus to Jugoslavia's mining industry. This company not only opened up the large lead-zinc mine of the same name, but through its exploration department was instrumental in discovering four additional lead-zinc mines in southern Serbia and Macedonia. This department, headed by Charles B. Forgan, accumulated a large fund of geological knowledge of the country as embodied in numerous reports and maps.

Friedensburg (12, p. 336) [2] has summarized the development of the Jugoslavian mining industry between 1913 and 1938 in the following table.

| Mineral | Unit of weight | Production in 1913 | Production in 1938 |
|---|---|---|---|
| Copper | Metric tons | 6,400 | 42,300 |
| Lead | Metric tons | (1912) 13 | 77,440 |
| Zinc | Metric tons | — | 39,300 |
| Antimony | Metric tons | 250 | 2,739 |
| Gold | Kilograms | 480 | 2,430 |
| Silver | Kilograms | 894 | 76,195 |
| Iron ore | Metric tons | — | 607,000 |
| Manganese ore | Metric tons | 5,000 | 4,000 |
| Chrome ore | Metric tons | 400 | 58,000 |
| Molybdenum ore | Metric tons | — | 19 |
| Pyrite | Metric tons | 8,000 | 150,000 |
| Bauxite | Metric tons | — | 405,000 |
| Magnesite | Metric tons | — | 39,000 |
| Rock salt | Metric tons | — | 74,000 |
| Bituminous coal | Metric tons | 57,000 | 450,000 |
| Lignite | Metric tons | 2,994,000 | 5,287,000 |

From this, it is apparent that the mining industry had made progress prior to the outbreak of World War II. Thus, Jugoslavia in 1938 was the largest producer in Europe of copper, lead, antimony, and chrome; it also produced significant amounts of pyrite, zinc, bauxite, and magnesite.

During the second World War, German troops occupied the country from 1941 to 1944 and utilized its mineral resources to a large extent for the war economy of Germany. Considerable investments were made at Bor and Trepča, as well as in chromite mines. A molybdenum deposit near the Bulgarian frontier was opened, but did not reach the production stage. Far-flung exploration activities contributed greatly to the knowledge of the country's mineral resources.

After the war, the communistic government was faced with the task of reorganizing the mining industry. All foreign enterprises were confiscated and nationalized; even all domestic mining operations were taken over by the government. Thus, the government is today the sole mining operator. Because war damages, with a few exceptions, were not severe, production at the mines was resumed in short order, but was limited by several factors. During the war, only the richest ores had been mined and development work had been neglected. Equipment was rundown and obsolete; skilled labor and experienced direction were lacking. On the other hand, the government was faced with the necessity of producing ore at any cost in order to obtain foreign exchange so essential for the execution of the Five-Year Plan. This dilemma

[2] Numbers in parenthesis refer to Bibliography at end of paper.

led to short-sighted measures, faulty dispositions, and a hand-to-mouth policy. Not until 1950 were these difficulties gradually overcome and to a great measure through American financial aid for the modernization of the mining industry. The Export-Import Bank granted a loan of 20 million dollars, of which 3.2 millions were allotted to Bor and 2.7 millions to Trepča for the most urgent replacements and improvements. Quite recently, some of the government control was relaxed and the mines were permitted to sell their products at free market prices.

In order to aid the mining industry and assist in the geological exploration of the country, the government in 1947 engaged a number of German technicians, most of whom now have returned to Germany. To take their places, newly established (since the war) institutes of technology have been able to provide the mining industry with their first class of graduates in geology and mining engineering.

All these developments have led to an increase in production, and at most mining properties the pre-war figures have been equaled or even exceeded. At those properties where output still is lagging, energetic measures are under way to overcome existing difficulties and impediments. It may be expected, therefore, that its mineral resources will enable Jugoslavia to build up a flourishing mining and smelting industry in the near future.

## GEOLOGICAL SETTING OF THE MINERALIZED AREAS IN JUGOSLAVIA

Exploration of the country from the standpoint of economic geology has barely begun so that only insufficient data as to its mineral deposits are available. Prior to World War II, native geologists were engaged chiefly in stratigraphic, paleontologic, and tectonic investigations. There were no economic geologists, however, and even today their number is strictly limited. Therefore, scientific studies of mineral deposits were conducted mostly by German, British, Austrian, and French geologists. A cross-section of the literature in this field thus shows many gaps and a lack of uniformity, this being particularly true as to genetic relationships.

Basic data have been shown on the Geological Map of Jugoslavia which was compiled by Kosta V. Petković in 1930–31 on a scale of 1 : 1,000,000. It is now considered out of date, and a new map prepared by V. Mikinčić is scheduled for early publication. Detailed geological maps of the major part of the country are not available. Its tectonic features, which are of such great importance for the understanding of the mineral deposits, are known in general outline only, so that much remains to be done in this field.

Older publications of economic geological nature are the one describing the work of F. Kossmat and his co-workers in Macedonia during World War I (30), and that of F. Katzer in Bosnia and Herzegovina (25). In more recent times, two German investigations are of significance. That of Schumacher-Stier-Pfalz (44) deals with the magmatic-tectonic features which control the distribution of ore deposits on the Balkan peninsula. A. Cissarz (3) outlines the geological environment of the country's mineral deposits and discusses a number of geological cycles with the mineral deposits related to these cycles.

It should be noted that due to the lack of fundamental data as to the geological make-up of Jugoslavia, these two publications should be regarded only as a provisional outline of the geological setting of the country's mineral deposits. This is also true for K. Stier's map (44) which depicts in a general way the tectonic and magmatic relationships of the mineral deposits on a scale of 1 : 3,000,000. This map is to be considered merely as a first attempt of a diagrammatic representation that omits many details. Significantly, however, this map, for the first time, subdivides the country into structural units; outlines the areas rich in mineral deposits, as well as barren regions; and demonstrates how both igneous activity and ore deposition are controlled by certain structural features. Inasmuch as both of these papers were published in Jugoslavian journals of limited circulation, their more important conclusions will be summarized as follows:

Most of the important mineral deposits of Jugoslavia are genetically related to igneous phases of several geological periods. The oldest period of ore deposition is coincident with Paleozoic intrusions of basic and acid magmas. This depositional period is not important unless the numerous occurrences of chromite are considered to be related to the intrusions of Paleozoic ophiolites, which is a debatable point. Kossmat and others believe them to be of Triassic or even Jurassic age. The granitic cycle of late Paleozoic age, which has been so productive of mineralization in Central Europe, has led only to minor ore deposition in Jugoslavia, such as gold-quartz veins. The same is true for the subsequent extrusions of quartz porphyry, which are widely spread throughout Bosnia. On the other hand, it is believed that the majority of the ore deposits of Bosnia—in particular the iron and copper occurrences—are related to the deeper phases of the quartz porphyry cycle which is presumably of Permian age. Genetic relationships in the Bosnian metallographic province, however, have not been fully clarified as yet, and it is possible that at least some of the deposits embraced therein are connected with the great igneous cycle of the Tertiary.

During the Triassic, eruptions of basic magma, as represented by diabase and melaphyre, and also by more acid rocks such as porphyrite, are significant in some districts. Here again, mineralization is slight. As mentioned in the foregoing, the assignment of the chromite deposits occurring in ophiolites to the Mesozoic era is still a matter of dispute.

Igneous activity on a grand scale began toward the end of the Cretaceous and reached its culmination during the Tertiary. Its initial phase, namely widespread plutonic intrusions of late Cretaceous and early Tertiary age, did not lead to extensive mineralization. This phase is represented by granodiorites, monzonites, tonalites, and similar rocks. Related to this period are pyrometasomatic iron ore deposits with magnetite as the principal ore mineral. They are of no economic significance, however. There followed an important metallogenetic epoch connected with extensive eruptions of andesite, dacite, and trachyte. To this period belong the most important nonferrous ore deposits of the country, such as numerous lead-zinc occurrences, led by Trepča, the large copper ore bodies at Bor and Majdan Pek, and many antimony, arsenic, and molybdenum deposits.

A study of Stier's map (Fig. 1) as to the arrangement and distribution of Jugoslavian ore deposition reveals that certain areas are deficient or even totally lacking in mineralization, whereas in other districts ore deposits are massed in zones or follow lineal trends. In the first group are the marginal areas of the Adriatic basin which extends from Trieste to the southern extremity of Greece. Most marked in their mineral deficiency are the Tertiary

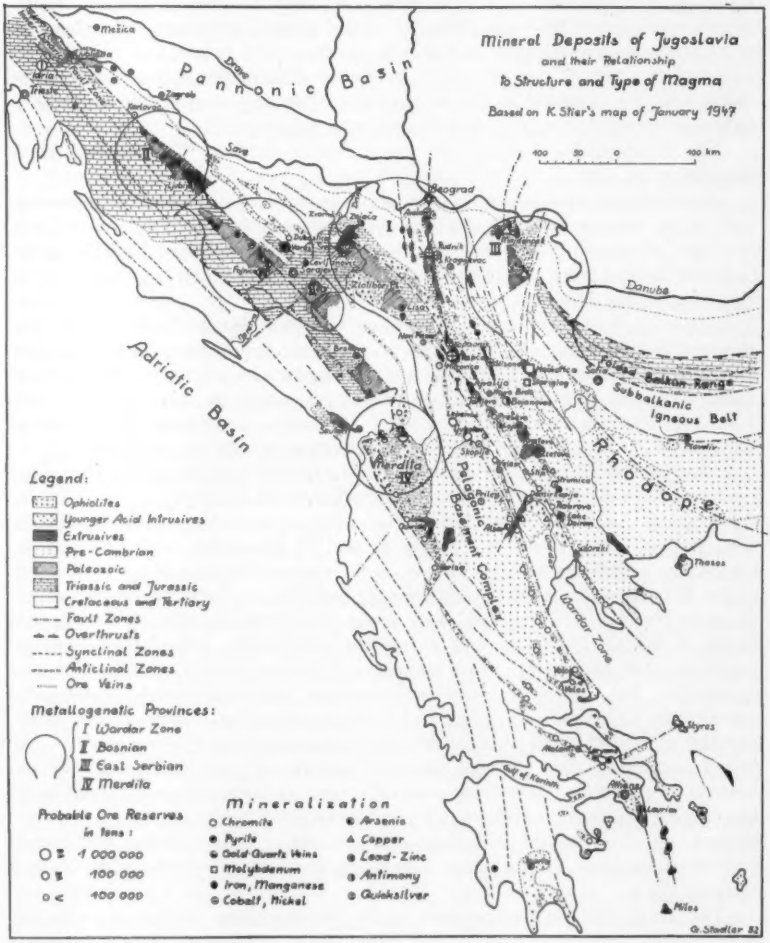


FIG. 1.

and Mesozoic belts of folding of the Karst region. Here only the bauxite deposits are of economic significance, but with their residual origin they need not be considered in this discussion of igneous relationships. Abundant mineralization, however, is found in the Inner-Dinaric mountain ranges of Bosnia, Serbia, and Macedonia. This fact may be attributed to the intense structural deformation of this region, which opened passageways for the upward movement of ore-bearing magmas and thereby created favorable conditions for ore deposition. On the other hand, there is again a striking dearth of mineralization in the large Pelagonic shield extending from Skoplje through all of Macedonia to the Gulf of Volos in Greece. The reason for this is to be found in the lack of deep-reaching structural deformation. Apparently this shield was not involved in the fracturing of the neighboring Wardar Zone, although its relative rigidity was favorable to deformation.

The relationships discussed in the foregoing lead to the following conclusions:

Areas of intensive mineralization occur along zones of incisive fracturing and strong magma intrusions; where these two conditions do not exist there is a decided dearth of mineral deposits. Thus, it is indicated that the areal distribution and zonal grouping of mineralization is intimately related to the major structural elements of the country.

Accordingly, the mineral deposits of the Jugoslavian Balkans may be grouped into three major metallogenetic provinces that encompass most of the important ore occurrences. These are (1) the tectonic trough of the Wardar Zone, (2) the East Serbian block-faulted mountain system, and (3) the Paleozoic limestone and schist complex of Bosnia, known as the "Bosnian Erzgebirge." The outlines of the three provinces are shown on Figure 1.

*The Wardar Zone.*—The distribution of mineral deposits within this zone conforms most clearly to the relations discussed in the foregoing.

Kossmat (30) describes the Wardar Zone as a wedge-shaped trough of the "graben" type, which is between 40 and 70 kilometers wide and can be traced in a northwesterly direction from the Gulf of Saloniki along both sides of the Wardar river valley beyond Skoplje and Kosovo Polje to the Ibar river in south Serbia. Geologically, it is made up of steeply dipping overthrust limbs of folded Paleozoic and older Mesozoic rocks. Ophiolites, mainly peridotite and serpentine, are common and enclose numerous chromite occurrences. In addition to these basic igneous rocks are widely distributed more recent intrusions of granitic and dioritic composition. Presumably, they erupted toward the end of the Cretaceous or during the Eocene epoch. As stated previously, this plutonic igneous activity did not lead to significant mineral deposition. Abundant mineralization, however, is connected with late Tertiary igneous activity, namely the eruption of andesites, trachytes, and dacites. A close spatial and genetic relationship exists between this event and the formation of the most important nonferrous ore deposits of the Wardar Zone.

The major belts of deformation in the Wardar Zone are found along its northeasterly and southwesterly margins where mountain-building stresses were most effective. Very pronounced is the great easterly marginal zone

of fracturing that extends from the Chalkidike peninsula northwesterly through Saloniki, Štip, and Trepča to the Drina river. East of the town of Kosovska Mitrovica a second fracture system branches off at an acute angle. It trends in a northerly direction across the Kopaonik Mountains toward Beograd. The large ore body of the Trepča Mine is located at the junction of these two major breaks. Intrusions of granodiorite and late Tertiary extrusions of andesitic, trachytic, and dacitic rocks have occurred along these systems. Several other important ore deposits are connected with these eruptions. Fissures parallelling the easterly marginal zone of fracturing also have been the loci of granodioritic intrusions and andesitic extrusions, which at many places were followed by hydrothermal solutions. In this manner, the Wardar Zone became the most important lead-zinc-bearing region of the country. Most of the antimony occurrences are found in proximity to these fissure systems.

*The East Serbian Metallographic Province.*—This area lies in the northwesterly extension of the Bulgarian sector of the sub-Balkanic belt of igneous activity. It is an overthrust block that has been block-faulted by two fault systems that trend northwest and northeast, respectively. Both systems are of Tertiary age, but not contemporaneous. Correspondingly, there are two separate andesite eruptions, the older located along the northwest fault system and the younger following the northeast fault zone. The earliest eruptions took place during the Senonian, but their majority occurred during later times, reaching into the Miocene epoch. Numerous fault systems have displaced this large mass of andesitic rocks and have served as passageways for rising hydrothermal solutions.

*The Bosnian Metallographic Province.*—This province has an extremely complex mineralization, as first described by Katzer (25). During the Austrian regime, it had considerable economic importance, but lost this position later due to diminishing nonferrous mining activities. It is still a large producer of iron ore, however. Its geological make-up differs considerably from those of the other two provinces. It has a core of Paleozoic schists, Carboniferous limestones and presumably Permian quartz porphyries. Tertiary extrusives, mostly dacite, were recently discovered. Structurally, this zone is characterized by the intersection of strong longitudinal elements with weaker cross-fissuring. The most important tectonic feature is the Inner-Dinaric zone of deformation which crosses the Paleozoic schist complex a short distance south of Sarajevo. It has a consistently northwesterly strike and may be traced for long, uninterrupted stretches. Its northwesterly extension, known as the Save Dislocation, passes through Karlovac and Ljubljana and reaches into the region of the Alps.

A number of mineral deposits are associated with this structural zone and the fault systems parallel to it. Its mineral content is complex and consists chiefly of copper, quicksilver, gold, antimony, arsenic, and iron ores. The most important of these, although now completely closed down, are quicksilver-bearing tetrahedrite occurrences and iron ore deposits. Among the latter, those in the Ljubija district of northwestern Bosnia constitute the most valuable iron ore reserve of Jugoslavia. Its ore bodies are quite irregular in

form and occur mostly as siderite veins of hydrothermal origin which cut across Paleozoic schists.

The geological age of this province is still uncertain. There is no apparent parallelism with the other two provinces because its relationship to the younger period of volcanism has not been determined as yet. Possibly, some of the ore deposits belong to the Tertiary, others to the much older Permian cycle of igneous activity.

The mineral deposits of Slovenia lie outside the three provinces discussed heretofore and belong in the Alpine system. They are represented by the important lead-zinc district of Mežica and the famous quicksilver deposit of Idria. Mežica is of Tertiary origin, while the genesis of Idria is quite uncertain.

The chromite occurrences of Jugoslavia present a special problem of genesis. Their age is a matter of dispute. We do know that they are older, possibly very much older than the Tertiary. In view of the wide distribution of the ophiolitic volcanism, it may be that these intrusions were not limited to any single epoch.

In summary, it may be said that Jugoslavia, as far as those parts are concerned that are important to its mineral economy, presents the aspect of a metallogenetic epoch which is associated with younger igneous activity. Its mineral deposits predominantly belong to the Alpine orogeny of the Tertiary period. Most of them show a marked relationship to andesitic, dacitic, and trachytic eruptions and represent their post-volcanic emanations.

The descriptions of deposits, which follow, are based chiefly on the author's course of economic geology which was given during 1950 and 1951 at the geological department of the Institute of Technology at Beograd. The description of the Trepča deposits has been abstracted to a large extent from the Trepča archives at Stari Trg. Supplementary information was furnished by mine operators and others.

## LEAD AND ZINC

Lead and zinc deposits are the most important of Jugoslavia's mineral deposits. During the past two decades, production has increased considerably chiefly owing to the development of the Trepča enterprise, as well as to the Mežica mine in Slovenia, which is an old and well established operation. Since the end of World War II, a number of medium- and small-sized operations have entered the ranks of lead-zinc ore producers; others are in the development stage. Production of these two metals may be expected to increase in the future. Jugoslavia during 1952 produced 1,265,000 tons of lead-zinc ore. In the same year the output of metals amounted to 67,100 tons lead, 14,400 tons zinc, 98,700 kilograms bismuth and 80,100 kilograms silver.

Geologically, most of these deposits, excepting those in Slovenia, show more or less intimate relationships to the Tertiary volcanism, that is to andesitic, dacitic, and trachytic lava flows. The last named commonly show propylitic alteration. Two types of ore bodies may be distinguished, namely fissure fillings and replacement bodies. The first group occurs in igneous rocks or nearby shales, some also in limestone. The other group favors the

contacts of limestone with igneous rocks or adjacent shales. An intermediate type is represented by lenticular or bedded deposits in shales, mostly in the vicinity of igneous rocks, and also by stockworks associated with fissures. At many places these different types grade into each other.

The most common ore minerals are galena and sphalerite. Although their ratio is variable, lead predominates at most occurrences, so that the lead production of Jugoslavia exceeds that of zinc. The deposits at Zletovo and Mežica contain little zinc. With the exception of Trepča, the zinc content of the ore bodies increases with depth. A few deposits yield more zinc than lead. A partial explanation may be that former operations have mined out the high-grade lead ores. An appreciable silver content is generally present and mostly associated with the galena. In some deposits, gold is found in recoverable quantities, the gold content at the Leze deposit being particularly rich.

Associated minerals are pyrite, at some places abundant pyrrhotite, to a lesser extent arsenopyrite and chalcopyrite, and rarely minerals containing antimony. Gangue minerals are primarily quartz in variable quantity and carbonates (calcite, dolomite, siderite, and in places abundant rhodochrosite), and secondarily barite. Contact-metamorphic minerals, mostly silicates, have been formed in limestone near igneous contacts, as for instance at Trepča.

Of the large number of known lead-zinc occurrences, only a few are of economic importance. There are only about twenty deposits that are being mined now, or are known to have been mined in the past, or are in the development stage at this time. The greatest number of these and particularly the most important ones are situated in the Wardar Zone. Kossmat has extended this zone in a northwesterly direction to the Drina River, so that it reaches from the Bosnian boundary on the north to the border of Greece on the south. Within this extended area, most of the mineral deposits are localized along the major zones of deformation, in particular along the eastern marginal zone of fracturing, its branch to the north and its parallel fracture systems. The most intensive mineralization has taken place in the area north and south of the town of Kosovska Mitrovica. Within it, and at the junction of the marginal fracture zone with its northerly branch, lies the Trepča mining district. Farther to the southeast are the deposits of Ajvalija, Janjevo, and Novo Brdo, and northwesterly those of Kopaonik and Rudnik. A decided differentiation into higher and lower thermal zones can be recognized. The former are representated by kata to mesothermal types and contain abundant pyrrhotite, marmatite, and some contact-metamorphic silicates. Typical of this type are the occurrences at Trepča, Kopaonik, and Rudnik. Accordingly, it appears that the Wardar Zone is underlain by an axial magma channel that gave rise to a central core of high temperature mineralization. It is surrounded by a marginal zone characterized by lower temperature mineralization because of deposition at greater distance from the magma. In the marginal zone, pyrrhotite is less abundant and is replaced by sulfantimonides. With increasing distance from the core are deposits carrying only antimony. In contrast to the latter, it is significant that Trepča shows only traces of antimony.

The description of the individual deposits, which is to follow, will be

divided according to the two groups defined in the foregoing, namely those of replacement bodies and fissure fillings, respectively. A comprehensive presentation of the lead-zinc deposits of Jugoslavia is found in the paper by Hermann and Mempel (16) which was written in 1939 and in many respects is obsolete today.

*Replacement Deposits*

*Trepča (Stari Trg Mine) in Southern Serbia.*—This district is the only one in Jugoslavia that so far has been studied adequately from a geological standpoint. The most important publications are those of Forgan, the former chief geologist of the Trepča (11, 47), and of Schumacher (42, 43), as well as a paper written in Slovenian (with a German abstract) by Nikitin and Duhovnik (35).

The Trepča district lies in the southern extension of the Kopaonik Mountains near the town of Kosovska Mitrovica in South Serbia. By air line, it is 210 km distant from Beograd, by rail 320 km. The deeply incised Trepča valley runs from Kosovska Mitrovica up to the mine of Stari Trg ("Old Market"). An aerial tramway, 6.3 km long, connects the mine with the town of Zvečan in the Ibar Valley. The power plant, flotation mill, the lead smelter and refinery, and the general offices are located there.

The structural control of this deposit has already been discussed in sufficient length. The country rock has been designated as the "Stari Trg Series," which is probably of early Paleozoic age. It is made up of phyllites with enormous inclusions of quartzite and recrystallized limestones. The ore deposit is contained in the latter. The whole series was subjected to intense orogeny during the early Tertiary period and in part prior thereto. Thus, the schists and limestones show intricate folding of the alpine type. The strike of the folds and the fracture zones are Dinaric, that is, in a northwest-southeast direction. The products of Tertiary volcanism are superimposed on the folded basement rocks. These volcanic rocks consist of great masses of lava flows and tuffs of trachytic and andesitic composition that erupted during the Miocene epoch.

In detail, the structure of this deposit shows a lenticular core of recrystallized limestone enclosed in a schist anticline (42, p. 16). During the Miocene, a pipe of intrusive rock was intruded into this structure. The pipe, which later provided a passageway for the ore-bearing solutions, constitutes a lateral apophyse of the main igneous plug and forced its way into the fractured crest of the anticline. It lies between limestone in the hanging wall and schist in the footwall and plunges at a constant angle of 37° along the axis of the anticline. Its cross-section is that of an irregular ellipse, the larger axis measuring more than 200 meters.

This pipe is made up of a coarse breccia which contains fragments of the basement rocks and, to a lesser extent, igneous material, indicating that it was caused by a gaseous blow-out (42, p. 19). It has a core of trachyte which has the shape of an irregular funnel. The trachyte was first altered to propylite and later kaolinized and partly silicified by hydrothermal solutions.

The ore deposit lies at the contacts of limestone with the breccia and

schists and was formed by replacement of the limestone. In the upper levels it may be compared to a trough of irregular shape that envelops the lower side of the breccia in the form of a horseshoe. With increasing depth, however, the deposit begins to feather out, following the limestone-schist contact and moving away from the breccia. Singewald (42) concludes that the massing of the ore along the contact of limestone with breccia indicates that this contact acted as a dam for the rising ore solutions.

The ore deposit so far has been opened up along fourteen levels of the mine. The highest of these has an elevation of 865 meters; the lowest, an elevation of 315 meters above sea level (42, p. 30). The average cross-section of the ore deposit measures 7,700 square meters between these levels. Above the 610 meter level it averages about 6200 square meters, but between the 610- and 375-meter levels, increases to nearly 10,000 square meters.

Mineralogically, the ore deposit is a very coarse, intimate mixture of argentiferous galena, ferruginous sphalerite (marmatite), pyrite, and pyrrhotite, with the two iron sulphides predominating. On the deeper levels, pyrrhotite forms large masses and increases with depth. Less abundant are arsenopyrite, chalcopyrite, and sulfantimonides such as boulangerite, bournonite, and jamesonite. Gangue minerals are quartz and a number of carbonates, chiefly calcite, dolomite, and rhodochrosite. At many places the ore bodies grade into limestone through irregular masses of carbonates which consist predominantly of rhodochrosite and are impregnated in variable degrees with sulphides, although rarely in minable quantities.

The contact metamorphic reaction silicates lievrite, andradite, hedenbergite, salite, etc., are older than the minerals discussed so far. Magnetite is associated with the silicates, which are abundant on the lower levels, this being particularly true of lievrite.

A characteristic feature of the ore deposit is the prevalence of crystal cavities. They give the ore bodies the texture of a sponge and are encrusted with well developed crystals that render the Trepča district one of the most interesting mineral localities of the world. Most remarkable are large, clean crystals of pyrrhotite, beautiful pseudomorphs of pyrite after pyrrhotite crystals, enormous dolomite crystals and aggregates of plumosite that protrude as delicate sheaves from the walls of the cavities.

The geological history of Trepča began during the Miocene epoch with a lateral bulging of the magma stock and its contact with limestone. The intrusive magma created intensive contact metamorphism in the latter and partially replaced it with the reaction silicates referred to. Subsequent events were the breakthrough of the igneous pipe, the formation of the breccia, and the intrusion of the trachytic core. A continuous series of post-volcanic processes ended this phase—at first propylitic alteration, then kaolinization, and finally intense silicification that created secondary quartzite. Ore deposition was initiated by high-temperature solutions that formed large masses of pyrrhotite. They were succeeded by waters of lower temperature whereby pyrite replaced pyrrhotite to a large extent. To this phase also belongs the formation of the main body of lead-zinc ores. The carbonates of the gangue material were laid down in a stage of still lower temperatures. Genetically

speaking, therefore, Trepča is an excellent example of a high-temperature, metasomatic lead-zinc deposit which is closely related to a late period of igneous intrusion.

*Historical and Economic Data.*—The earliest reports on mining extend back to the year 1303. During the fourteenth, fifteenth, and sixteenth centuries the main deposit and smaller occurrences nearby were subjected to flourishing mining operations which, however, ceased entirely during the seventeenth century. The modern enterprise began in 1927 with the formation of the "Trepča Mines Limited." Actual production started in 1930. Since that time, Trepča has developed rapidly into one of the greatest lead-zinc producers of the world.

Schumacher has supplied figures as to tonnages and grades mined during the period from 1930 to 1944 (42, p. 48). For the years 1945 to 1950, these data are as follows:

| Year | Ore mined, metric tons | Grade of ore % Pb | % Zn | Ag grams/ton |
|---|---|---|---|---|
| 1945 | 103,656 | 7.3 | 3.1 | 100 |
| 1946 | 427,749 | 6.8 | 3.5 | 98 |
| 1947 | 486,634 | 6.9 | 5.0 | 85 |
| 1948 | 531,574 | 7.2 | 5.5 | 86 |
| 1949 | 634,266 | 6.6 | 5.0 | 88 |
| 1950[3] | 665,191 | 6.5 | 4.8 | 94 |

The total production of ore mined for the years 1930 to 1950 was 10,047,540 tons averaging 8.2% Pb, 5.6% Zn, and 102 grams Ag per ton.

The metal content of all ore mined from 1930 to 1950 is computed at 825,000 tons of lead, 566,000 tons of zinc, and 1,022,000 kilograms of silver. Bismuth was produced in about the same amount as silver; it, too, occurs with galena. In 1950, the average composition of the ore mined was: 6.5% Pb, 4.8% Zn, 0.11% Cu, 0.76% As, 26.6% S, 31.1% Fe; in addition it contained 94 grams of silver and 107 grams of bismuth per ton of ore. The gold content is so small that it cannot be recovered.

The two principal metals have shown the following changes with increasing depth of the mine: The lead content decreased slowly and fairly regularly from 9 to 10 percent at the beginning to 6 to 7 percent during the last years. The zinc content decreased from 8 to 9 percent at the beginning rapidly to 2 to 3 percent at the end of World War II and again increased considerably since 1945 so as to reach an average level of 5 percent during the last few years. These changes in the zinc content came about through technical reasons and may be explained by changes in mining practices in regard to different ore bodies and their respective distances from the breccia. Those bodies closest to the breccia show a decrease in lead and zinc content with increasing depth of mining, this being particularly true for zinc; whereas the zinc content remains constant with depth in those bodies that are more remote from the breccia. Because the first named furnished most of the production prior to 1944, the zinc content dropped up to that year as mining operations reached the deeper levels. After 1944 increasing proportions of the total tonnage

[3] In 1951, the tonnage is said to have reached 700,000. Prior to that, the maximum production was 698,760 tons in 1939–1940.

came from ore bodies farther away from the breccia, which contained higher zinc values. The ore deposit thus shows not only vertical but also horizontal zoning dependent upon the position of individual ore bodies in relation to the breccia.

Proven ore reserves as of January 1, 1950, were 3,652,000 tons with 6.9% Pb, 4.2% Zn, and 118 grams Ag per ton. Nearly all this tonnage is on the lower levels of the mine as the levels above the 610-meter horizon have been mined out. A progressive decrease in values with increasing depth of mining is to be expected.

*Kopaonik (Vojetin Mine), Southern Serbia.*—This deposit, which was also developed by the Trepča Mines Limited, lies about 30 km north of Trepča in the central part of the Kopaonik Mountains near the crest of Suvo Rudište, 2,017 m high. An aerial tramway, ten km long, connects the mine with the railroad station of Lešak in the Ibar Valley. This operation was started shortly before the beginning of World War II, but closed down again in 1941. The plant was totally destroyed during the war. It was rebuilt, and production was resumed in 1949. The main haulage tunnel lies at an elevation of 1,000 above sea level. The principal production levels are between 1,100 and 1,300 m. They have opened up an old mining area with hundreds of caved shafts, some of which are 200 m deep.

Not much is known about the geology of the Kopaonik Mountains. A publication by Wilson (48) deals with the geology and the structure of a part of these mountains. The Suvo Rudište formation is the oldest and makes up the core of the mountains. It consists of a more or less metamorphosed phase of early Paleozoic sedimentary rocks. They are chiefly phyllitic and chloritic schists and also recrystallized limestones overlain by massive limestone beds (Vojetin limestone), which are considered to be of Ordovician age and which have been intruded by serpentine. The younger sediments consist mainly of sand-stones belonging to the Flysch formation. During early Tertiary times, a large stock of granodiorite was intruded, associated with andesites and tuffs of Miocene age. There is an intimate relationship between the andesites and ore deposits. Structurally, the latter lie within the sphere of the northerly branch of the Wardar Zone close to the junction with the eastern marginal zone of fracturing.

The ore deposit is similar to Trepča, but the breccia is missing. The ore is of metasomatic origin localized along a limestone-andesite contact. The limestone has been intruded by a large andesite stock and marbleized. Good underground exposures reveal two small apophyses branching off the stock. One of these is of the chimney type and extends along a limestone-serpentine contact; the other is more tabular in shape and contained only in limestone. The ore bodies occur along the contacts between andesite and limestone, and in the footwall in the case of the chimney, but in the hanging wall in the case of the other intrusive body. The largest ore bodies are connected with the andesite chimney. Their shapes are those of irregular stocks or pipes; their cross-sections vary from a few square meters to areas several hundred square meters in size. Mineralization consists of argentiferous galena, high-iron sphalerite, pyrite, and pyrrhotite with lesser amounts of arsenopyrite and

chalcopyrite. The content of arsenic fluctuates greatly and reaches 10 percent. With increasing depth, the values decrease rapidly, and the ore body appears to grade into a body of massive pyrite and pyrrhotite.

At some places are zones of "gossan," mostly connected with fractures. They resemble normal oxidation zones and are made up of masses of brown limonite, some of which are soft and crumbly; others are harder and vuggy owing to silicification. Most of the "gossans" carry practically no values, and only a few contain recoverable lead-zinc ore. It is significant that commonly they are found contiguous to sulphide bodies and follow these down to considerable depths. These circumstances have led to one conclusion that the "gossans" are of primary rather than secondary origin and that they were formed by a kind of "auto-oxidation" through ascending solutions and water vapors. The author, however, believes that they constitute true oxidation zones that penetrated to greater depths along fissures. Judging by their composition, they probably were pyritic or sideritic masses originally.

According to British figures for the year 1938, the ore reserves were 750,000 tons containing 9.2% Pb, 6.5% Zn, 3.3% As, 0.16% Cu, 117 grams Ag, 42 grams Bi, and 0.5 grams Au per ton of ore. The highest gold values (up to 4 grams) have been found in ore bodies rich in arsenic, and this indicates that arsenopyrite carries the gold. It is hoped that further development work in some promising areas will increase the ore reserves considerably. Present production is about 11,000 tons of ore per month, which are smelted at Zvecan. This makes the Kopaonik property the second largest lead-zinc enterprise of Serbia.

*Novo Brdo, Southern Serbia.*—Novo Brdo is situated in a difficultly accessible mountainous area of southern Serbia. This mining district lies southeast of the provincial capital of Priština between Kosovo Polje (Field of the Blackbirds) and the Morava River valley. It is 60 km distant from Trepča. During the Middle Ages, particularly between the twelfth and fifteenth centuries, it was considered the largest mining center of Serbia. It is said that during the fourteenth and fifteenth centuries Novo Brdo was the largest and finest city of the entire Balkan Peninsula. It was also an important trading center with its own mint. Mining was carried on mainly for silver and, to a lesser extent, for gold. In 1441, the city was captured by the Turks and destroyed. Mining declined and ceased entirely toward the end of the seventeenth century.

In view of its former prominence, this district was carefully explored by the Trepča Mines Limited between 1927 and 1938. Some ore was opened up, but work was suspended in 1938 because this tonnage was considered insufficient for the resumption of mining operations. In 1950, however, the mine was reopened for the purpose of recovering the ore developed by the British company.

The geological setting is comparatively simple. Large masses of limestones are overlain by phyllite and quartz-sericite-schists. This series is of Paleozoic age and was intruded by Tertiary andesite which also was the source of the ore.

During the main Tertiary period of folding, the limestones and schists were compressed into a system of anticlines and synclines with their axes striking

in a northwest-southeasterly, that is Dinaric, direction. It is remarkable how the ancient operations had been guided by the regional structure, as long stretches of caved workings can be seen paralleling the crests of anticlines. Novo Brdo, therefore, is a good example of close relationship between structural elements and ore deposition.

British engineers have explored these andesite bodies between the 635 and 950 meter levels and were able to outline within the andesite a fairly large body of sulphide ore. It is about 250 m long and has a maximum thickness of more than ten m. Contrary to expectation, the ore body did not continue to greater depths, but wedged out and was replaced by a great mass of "gossan" along the andesite-limestone contact. The "gossan" contained little or no lead, but locally fair zinc values. As a whole, it did not constitute ore.

Development work proved an ore reserve of about 300,000 tons with an average tenor of 5.2% Pb, 11.1% Zn, 108 grams Ag, and 2.7 grams Au per ton of ore. The principal ore-bearing minerals are argentiferous galena, sphalerite and pyrite. The high gold values are carried mostly by the pyrite. Chances are slight that additional reserves can be developed at greater depth. Novo Brdo has not lived up to the expectations aroused by the enthusiastic accounts of its former richness.

*Rudnik, Central Serbia.*—Rudnik is located about 70 kilometers south of Beograd in the Sturac or Rudnik Mountains, which rise to an altitude of 1,132 meters. Structurally, the district lies astride the northerly branch of the Wardar Zone which extends from Trepča across the Kopaonik Mountains and through Rudnik to Beograd.

All the deposits lie within the Cretaceous basin of Rudnik which is made up chiefly of flat-lying, lower Cretaceous sediments, namely limestones and interbedded shales, sandstones, and conglomerates. These beds have been penetrated by dikes and stocks of late Tertiary andesites and dacites. Mineralization is localized not so much along the contacts of the larger stocks, but rather within the marginal zones of relatively thin dike-like intrusions. The last named invaded strongly faulted sediments along fracture zones which strike mainly southwest-northeast and southeast-northwest. As a result, there developed, principally in limestone, parallel fissuring and local mylonitization which served as passageways for the ascending ore solutions. At many places, mineralization is also found along a system of younger fissures which crosscut the andesites.

The ore was deposited mostly within limestone, but locally also in andesite. Only rarely is ore found directly on the igneous contact. Marlstone and sandstone beds, which are interbedded with the limestones, are mineralized only to a lesser extent; shale beds are mostly barren.

The country rock next to the ore bodies has been intensively altered. Alteration increases where the rock is shattered. Silicification predominates and may result in the formation of secondary quartzite. Kaolinization is widespread, too. Along the contacts of andesite with sedimentary rocks, reaction silicates have been formed which consist principally of diopside, tremolite, and actinolite.

The ore deposits are replacement bodies in limestone (Jezero type) and fissure fillings (Bezdan type).

*Mežica (Miess), Slovenia.*—Mežica, which was called "Miess" under the Austrian regime, is the largest of the Slovenian lead-zinc deposits. It is one of a series of replacement deposits that occur in Triassic limestones of the eastern Alps within the former Austrian province of Carinthia. In this series also belong the Bleiberg deposit, which is still a part of Austria, and Raibl (Cave di Predil), now belonging to Italy. At Raibl, zinc is the predominant metal, whereas lead is the chief product of Bleiberg and Mežica. Geologically, all three are quite distinct from the Serbian lead-zinc deposits, inasmuch as they show no immediate relationship to igneous rocks. They were formed at greater distances from igneous activity and represent a meso- to epithermal type of replacement ore. Their genesis is attributed to a deep-seated igneous stock which extends in a west-easterly direction under the entire zone of mineralization. The age of the mineralization is considered to be Tertiary.

Mežica lies in a mountain range of the eastern Karavanks close to the Austrian border. It is about 50 km distant from Ljubljana, the capital of Slovenia, in a northeasterly direction. The ore deposits are found in the upper section of the Wetterstein lime, a part of the Alpine Triassic. The hanging wall of this limestone, also known as the "ore lime," is formed by the Cardita formation which acted as a dam for the rising ore solutions. Generally, the ore does not occur directly on the contact between these two formations, but mostly about 50 m below it. Owing to intense folding and faulting, ore deposition is very complicated (14).

The individual ore bodies occur as very irregular pipes in limestone (24). Their cross-sections are small and may not exceed four to ten square meters. Areas of 50 to 100 square meters are uncommon. Their vertical extent is quite limited, too. Commonly, they die out at depths of 30 to 40 m; only a few pipes maintain their values beyond a depth of 200 m. On account of such small dimensions, the average pipe does not contain more than a few thousand tons of ore. On the other hand, numbers of the pipes are grouped together, and such groups again aggregate to form an ore-bearing section. The most important of these is Igerčevo (Igertsberg). Most of the pipes are localized along the intersections of bedding planes with joints standing more or less at right angles to the former. Due to the irregular occurrence of the pipes and their small dimensions, development of these ore deposits is extremely difficult and costly.

Mineralization took place in three phases: first, introduction of dolomite and barite, then deposition of galena, sphalerite, wurtzite, pyrite and marcasite, and finally a second phase of carbonate and barite formation with a little fluorite. This paragenesis indicates an epithermal type of deposit (24, p. 717). The ores often have a beautifully banded texture.

Mežica was already an important producer before World War I. In 1913, nearly 7,000 tons of lead were produced; in 1916, nearly 13,000 tons. After this war, the property was taken over by the British "Central European Mines Limited"; after World War II, it was nationalized. The ore was treated at its own smelter located at Žerjav near Mežica. For many years,

the metal content was about 11% Pb and 1 to 1½% Zn. More recently, the lead content has gone down materially with a lesser increase in zinc value, so that at present the ore contains about 6% Pb and 2½% Zn. The production of wulfenite concentrates reached its maximum in 1912 with 146 tons, but has dwindled to a small amount.

### *Lead-Zinc Veins and Bedded Deposits*

Lead-zinc veins and associated bedded deposits commonly show a close relationship to andesitic and dacitic rocks. Particularly this is true for the Wardar Zone where most of them occur all the way from the border of Bosnia to Macedonia. The most important of these deposits are described, beginning with the most northwesterly ones and proceeding in a southeasterly direction.

*Srebrenica, Bosnia.*—The ore district of Srebrenica (meaning "silver town") lies in eastern Bosnia near Ljubovija. This is a very old silver mining district which began operating during Roman times and flourished until the fourth century B.C. During the fourteenth century, Srebrenica again was a famous mining area, but declined during the Turkish regime soon thereafter. Prospecting activities were resumed about 1880.

The literature is old and meager (40). The ore district is made up of Paleozoic sediments, chiefly phyllites and argillaceous shales. Quartzites and quartzitic schists are also found. These beds have been invaded by late Tertiary andesites and dacites, some of which have been propylitized. The belt has been folded in the Dinaric direction and cross-cut by numerous fissures bearing northeast. The ore veins follow the fissure system and are commonly confined to the igneous rocks; rarely they occur in the surrounding schists.

More than 30 individual veins are known. The more important ones are grouped in a vein system that can be traced northeasterly for about three km. The widest veins show many diagonal, parallel, and cross branches. Mostly, they have definite walls, and the andesitic country rock is strongly kaolinized. The fissures are filled with fragments of the country rock, galena carrying up to 4,000 grams of silver per ton, and sphalerite. Associated minerals are pyrite in variable quantities, arsenopyrite, chalcopyrite, and a few antimony sulphides. Siderite is the most common gangue mineral. Locally, the ore minerals are found as cementing an andesite breccia, and at such places gangue minerals are scarce or missing.

Ancient mining operations were confined to massive galena ores; sphalerite and mixed ores were left. Numerous shafts, tunnels, waste dumps, and slag dumps bear witness to the skill with which the "Saxons" of former times mined the veins to the level of the valley floor. A large caved stope resulting from their activities has a depth of about 13 m.

*Avala near Beograd.*—Avala is one of the smaller lead-zinc occurrences of Jugoslavia. It is located about 20 kilometers south of Beograd in the north fork of the Wardar Zone, which branches off the large eastern marginal fracture zone at Trepča. Here also, literature is practically nonexistent (6). The following description is based on information furnished by Dr. K. Stier,

a recent investigator of this deposit. During the years immediately preceding World War II, the French Société des Mines de Bor prospected and developed it, which led to small-scale production a short time ago.

The ore deposits have been developed by adits and winzes along the foot of the southern slope of Avala Mountain to a horizontal extent of 600 m and vertically to 200 m. They occur in an area that has been structurally deformed and, in the main, are localized near a breccia zone that strikes in a westerly direction. This zone, which is more than 600 m long and one to ten m wide, has faulted lower Cretaceous sediments in the vicinity of andesite intrusions of Miocene age. The ore deposition is related genetically to the igneous intrusions. In the mineralized area, the sediments have been slightly domed, overthrust at flat angles, and faulted. The most intense fracturing and mineralization have taken place in Cretaceous limestones along two fissure systems. Where these fissures intersect, small, irregular replacement bodies were formed in limestone, this being particularly the case in the upper levels of the "Slavia" mining subdistrict. Such ore bodies are several meters wide and constitute about 25 to 30 percent of the total mineralization of the Avala region. Some of them have been mined in ancient times.

The best ore was found in a composite vein containing three to four parallel stringers and ranging from one to three m in width. This vein is located in the hanging wall of the breccia zone and intersects the latter at an acute angle. It is mineralized only in limestone and sandstone and is barren when passing through shale, so that less than one-half of its area is in commercial ore.

Of special interest is pyrometasomatic mineralization that is found about 200 m distance from the breccia zone along the contact of an andesite dike with silicified limestone. These deposits occur in the shape of nests about the size of a football and contain galena and sphalerite, as well as contact-metamorphic reaction silicates such as epidote and axinite. Thus, a high temperature genesis is indicated.

Ore minerals in the Avala district are principally argentiferous galena and sphalerite rich in iron. Associated sulphides are pyrite, arsenopyrite, and some chalcopyrite. The gangue consists of quartz, calcite, and fragments of country rock. Prior to 1940, a German company mined about 100,000 tons of ore which averaged 9% Pb, 5% Zn, 2% As, 0.3% Cu, and 220 grams Ag per ton. Additional ore can be developed.

*Leze (Šlisane), Southeast Serbia.*—Very little has been published about this ore deposit. It is located in a remote mountain area about 30 km west of Leskovac. There a core of crystalline rocks has been invaded by younger andesites which, in turn, are crossed by veins of ore. Associated with the main vein are several subsidiary veins. It is a quartz vein and carries the best ore at its junctions with the lesser veins. Sphalerite is the predominating ore mineral and is associated with galena and pyrite. An increase of the zinc content is believed to occur with increasing depth. This deposit is characterized by unusually high gold values which are found partly as free gold in quartz and partly as admixture of the sulphides. The average tenor of the ore is 3 to 4% Pb, 6% Zn, and 8 grams Au per ton.

There are four ore shoots: Ore No. 1 is 75 m long and 2 m wide with

reserves of 40,000 tons with a tenor averaging 3.7% Pb, 7.6% Zn and 7 grams Au per ton; No. 2 is 200 m long, 5 to 7 m wide, and has an ore reserve of 300,000 tons containing 3.2% Pb, 6.1% Zn and 8.9 grams Au per ton; No. 3 is 80 m long, 2.5 m wide, and averages 1.4% Pb, 3.5% Zn and 9.5 grams Au per ton; No. 4 is 55 m long and 6 to 7 (?) m wide.

These tonnages and grades indicate a valuable deposit. Presumably additional reserves can be developed, and mining operations are now on the way.

*Zletovo, Macedonia.*—This is the most important vein deposit and has the largest reserves of lead-zinc ore. It lies about 30 km north of Štip, and 60 km from Skoplje, the literature is sparse (2).

Zletovo is located in an outlying area of the Rhodope Shield. It is a typical vein deposit and is related to the dacitic stock of Kratovo-Zletovo which has an area of 1,000 square km, rendering it one of the most extensive igneous intrusions of the country. These dacites locally have been altered to propylite. Within the igneous rocks, 17 veins are known which occur as a vein system more than two km wide. As a whole, the individual veins are parallel, but some of them split into two branches. The general strike of the vein system is northwesterly.

Development and mining operations are conducted through the adit of the Dobrevo Mine. Most of the current production comes from the main vein which has been opened up for 1,300 m along its strike, although it is not productive over the entire distance. The average width of this vein is 2 m, but locally it increases to more than 6 m. Kaolinization of the dacite is so intense that the ore contains as much as 10 to 20 percent kaolin.

Galena is the most important mineral; sphalerite, pyrite, and a little chalcopyrite are also present. The principal gangue mineral is siderite, which carries a high manganese content, namely 17 percent. Other gangue minerals are rhodochrosite, calcite, and quartz. On the upper levels, abundant barite was found, which was famous for its large crystals of yellow color with white borders. Locally, galena occurs as dense masses of great purity. The best ore shoot of the main vein was about four m wide and carried 110 cm of pure galena. Thicknesses of several decimeters of pure galena are not uncommon. Some of the lesser veins also show good galena values; others are known for their richness in zinc.

The average tenor of the ore produced during the earlier period of mining was 11 to 12% Pb and 1 to 2% Zn. Mining operations in this district extend back to Roman times. Reference was made already to the existence of a well preserved Roman tunnel which is decorated with antique sculptures. Large slag dumps indicate that mining flourished also during the late Middle Ages. Soon after World War II, mining operations were resumed based on an estimated ore reserve of 750,000 tons which previously had been developed by the British Zletovo Mines Limited. Conditions are favorable for the opening up of additional reserves within this extensive vein system.

While Zletovo and Leze lie outside of the Wardar Zone proper, it is probable that they belong to a fissure system that parallels the easterly marginal fracture system of the Wardar Zone and which contains not only lead-zinc but also antimony deposits. The Ajvalija and Janjevo deposits, however,

are also part of this great fracture zone. They vary from those described in the foregoing by the fact that they are not true fissure fillings, but are bedded deposits and impregnations.

*Ajvalija near Priština, Southern Serbia.*—This deposit is situated along the eastern margin of the Kosovo Polje (Field of the Blackbirds) about five km from Priština. The French Société des Mines de Bor had explored and developed the deposit before the last war. The discussion which follows is based on information contained in the Trepča archives, and, in particular, on reports by French experts.

Ore deposition is localized in a broad belt of quartz-sericite schists that are flanked on both sides by darker phyllites. Owing to intense folding and fracturing, conditions are complicated. The ore deposits are confined to a limestone horizon that is interbedded with sericite schists. Through tectonic movements, the limestone has been rolled out and broken up, so that now it consists of a series of irregular slabs; the mineralized zones also show this irregular character.

Based on their form, the ore deposits may be classified as three types:

(a) Fillings of lenticular or saddle-shaped cavities which were the result of stresses applied to folder beds of varying elasticities, in this case, limestones and schists (saddle reefs).

(b) Stockworks formed by ore deposition in irregular networks of joints and fractures within calcareous and schistose country rocks.

(c) Metasomatic bodies due to replacement of limestone slabs by ore.

Due to extreme faulting, these processes did not lead to the formation of larger, compact ore masses, but created a number of isolated and irregular ore bodies of small vertical and horizontal dimensions. This irregularity and discontinuity of the ore occurrence greatly handicaps the development and exploitation of the district.

Taken as a whole, this deposit constitutes a mineralized fracture zone that probably follows the crest of a minor fold. It has the character of a lode that is made up of many lenses, pockets, nests, and veinlets of ore, with a total length of about 300 m. Some of the individual bodies are massive ore, others consist of impregnated schist. The width of the lode ranges from a few meters to more than 40 m, including the mineralized schist areas.

A complex mixture of sphalerite with lesser amounts of galena, pyrite, and marcasite constitutes the ore. Quartz and carbonates are gangue minerals. The median metal content of the massive ore bodies is estimated at 7 to 8% Pb and 15% Zn. That of the mineralized schist areas varies a great deal, but most of them are low grade. The ore also carries a moderately high silver content (about 100 grams per ton) and a gold content of about 0.8 grams per ton. In addition, it averages 1 to 2% arsenic and 0.2% copper.

It is difficult to estimate the ore reserves in view of the irregularity of the ore occurrences and the lack of detailed mapping. Additional development work should lead to the blocking out of reserves aggregating several hundred thousand tons of good lead-zinc ore.

Geologically, this deposit is a rare example of ore deposition in cavities caused by the folding of strata that vary considerably in hardness, and through

metasomatic replacement of limestone slabs. No Tertiary igneous rocks are known in the district; therefore it must be assumed that the andesite stock at nearby Janjevo extended as an underground spur into the Ajvalija area, which there invaded the schist anticlines and became the source of the ore. Mining operations began only recently in this district.

*Other Deposits.*—Hiessleitner (19), Murray-Hughes (34), and the Trepča archives yield information on the Janjevo deposit near Priština in southern Serbia where Tertiary andesite intrudes schist and limestone to yield the Prlina replacement deposit of argentiferous galena in phyllite and schist, and the Kišnica low-grade disseminated lead-zinc deposit. The last appears to contain several million tons of low-grade lead-zinc ore amenable to open cut operation.

Other deposits occur at Brskovo and Šuplja Stena in Montenegro which Cissarz (3, p. 44) connects with Triassic intrusions. The last named deposit is said to contain 440,000 tons of ore averaging 9% Pb and 16% Zn.

## COPPER

Although a number of the lead-zinc deposits contain a small amount of copper (between 0.1 and 0.3%) and Rudnik carries as much as 1 percent, this production of copper is not an important factor in the economy of Jugoslavia. Future output of this metal will be based solely on the two large deposits of Bor and Majdan Pek. Both belong in the East Serbian metallographic province and are connected with the andesitic igneous activity of this area.

### *Bor, eastern Serbia*

Bor is located in the area between Serbia, Rumania and Bulgaria within 30 km of the Bulgarian border. It is about 150 km distant from Beograd. The mine is connected by a railroad with Metovnica.

There are no comprehensive reports of recent years available. The most important publication, that by Lazarevic (31), is more than 40 years old. Of more recent age are two short papers by Heise (15) on the structure of the district and a short abstract of the geology by Mempel (32). Pavlović (36) describes some microscopic investigations of the ore.

The ore deposits lie within the East Serbian batholith of andesitic composition. Its north-south axis is about 80 km and the east-west axis more than 20 km long. It covers an area of around 800 sq. km. The earliest igneous activity took place during the Senonian, but the main mass is as late as Miocene.

Structurally, the area is characterized by large overthrusts that occurred in post-Senonian time, whereby limestone and marlstone strata of Mesozoic age were transformed into decken or overthrust sheets. Subsequently, the intruding andesite destroyed them except for a few remnants that now rest without roots on top of the batholith. These movements recurred until fairly recent times along two main lines of structure, which trend in west-northwesterly and north-northeasterly directions, respectively.

The great mass of the intrusive rock is a fairly fine-grained andesite. Within it is a later intrusion of a hornblende-biotite andesite that has a coarsely

porphyritic texture; some of the hornblende crystals are more than 20 mm long. This type of rock is found only at Bor and the copper deposits occur only in it, so that a genetic relationship is indicated by its presence.

The batholith is traversed by two intersecting fissure systems at whose intersections extensive propylitization has taken place. The ore bodies, too, have a spatial relationship to these fissure systems and occur at the junction of two faults paralleling them. Thus, structure, propylitization and mineralization are closely related.

The ore bodies are silicified and mineralized masses within the propylite, which surrounds them like an aureole. They were formed by an intense replacement of the shattered country rock. The silica content of the rock was re-distributed, thereby causing widespread silicification. The country rock of the Tilva Mika ore body is such a silicified propylite; within its groundmass the outlines of the original biotite and hornblende crystals still can be recognized. The strongest evidences of silicification are the so-called "quartz hats" that rise as steep hills above the surrounding terrain owing to their resistance against erosion. They consist of more or less porous and spongelike quartz skeletons in which casts of dissolved crystals can still be seen. They represent the leached oxidation zones of sulphide ore bodies.

The mineralization at Bor occurs as three large closely spaced ore bodies:

(a) *Cuka Dulkan* (meaning Cuka Hill) was discovered in 1902, as the first of the three occurrences, and is the only one hitherto described in the literature. Its cross-section is elliptical with a long axis of 300 and a short one of 130 meters. In vertical section it has the shape of a wedge standing on edge. The open pit operations that supplanted the former underground mining have created a large funnel-shaped excavation about 100 meters deep. The ore body is a brecciated mass containing predominantly pyrite, with covellite and enargite. The highest grade ore is found in the core of the body where replacement has been complete; the marginal zones are of lower grade. Formerly the average grade of the ore mined was between 5 and 6 percent Cu, but is now only about 4 percent due to exhaustion of the richer ore. The ore body is surrounded by a halo of altered andesite with an inner zone of kaolinization, and an outer zone of "roche verte," which grades into unaltered andesite. Only at its southwestern side does the ore border on fresh andesite because it is cut off by a fault. This fault also is the reason for the wedge-shaped form of the ore body. Formerly, before it was removed by mining operations, a "quartz hat," 40 to 50 meters high, sat on top of the Cuka Dulcan. It had a low content of gold, which was never recovered due to lack of recognition.

(b) *Tilva Mika* (Tilva being the Rumanian word for hill) was discovered in 1912. Actually the deposit embraces several separate ore bodies with intervening propylitic zones. Pyrite is the predominating mineral accompanied by much covellite, considerable chalcocite, and lesser amounts of bornite and chalcopyrite. Here also, the marginal zones are of lower grade than the cores. Formerly, the copper value was about the same as that of Cuka Dulkan but now has dropped to about 3 percent. The country rock is a silicified propylite. The deposit is topped by a mass of fine porous silica

that extends down into the underground mine where it wedges out. This capping contains no copper and practically no gold.

(c) *Tilva Roš* (Red Hill) is the landmark of Bor because it forms a bare hill of reddish color about 180 m high. The hill is a typical "quartz hat," as it is made up of coarse, porous, friable silica. Because it averages 2.4 grams gold per ton the management plans to mine it as gold ore. In depth the body of silica changes into a siliceous sulphide ore body containing only pyrite and chalcopyrite and carrying 0.8 to 1.0 percent Cu. About 10 million tons of this material are available.

Development work on the lower levels as yet has not furnished adequate information as to the roots of the Bor deposits. The ore body of Cuka Dulkan appears to wedge out at depth. The individual ore bodies of Tilva Mika either break up into a network of pyrite veinlets or grade into pyritic impregnations. In both cases copper values drop rapidly with depth, which seems to indicate that the roots of this deposit have been reached.

Genetically, Bor is a good example of a sub-volcanic ore deposit that was formed fairly close to the surface under mesothermal conditions. This is shown by the various alterations of the country rock and the small vertical extent of the ore bodies. Although their mineralization is quite different, the Bor deposit resembles the gold occurrences of Rumania within the Carpathian arc, which are also connected with propylitized igneous rocks. All are characterized by the presence of enargite, which seems to be a common mineral of the Tertiary volcanism in eastern Europe. As shown by Schneiderhöhn and Ramdohr (32, p. 553) and by Cissarz (3, p. 46) covellite and chalcocite, contrary to former conceptions, are not products of secondary enrichment, but mostly are of hypogene origin, probably through alteration of enargite.

The ore bodies at Bor were subjected to post-mineral faulting along rejuvenated pre-mineral fissures, and thus differ from Trepča and most of the other mineral deposits of the Wardar Zone. This led to segmentation of the ore bodies and the formation of shattered zones and ore breccias.

*Historical and Economic Data.*—Bor was discovered incidental to gold placer operations. After World War I the French Société des Mines de Bor developed it into the largest copper mine of Europe. Its maximum production of 43,600 tons of copper was attained in 1940. In 1952 production was 32,800 tons of copper from 1,265,000 tons of ore. The grade of ore in 1953 was 2 percent. According to reports more than one billion dinars (about $3,300,000) will be invested during 1952 in the mines and reduction plants of Bor, principally to increase the annual capacity of the electrolytic refinery to 36,000 tons of copper. It also has a substantial gold production as the blister copper contains 40 grams Au and 140 grams Ag per ton. When the auriferous silica deposit of Tilva Roš is mined, Bor may become one of the largest gold producers in Europe.

According to German computations, in 1948 the ore reserves were as follows:

| | | | |
|---|---|---|---|
| Cuka Dulkan: | 5,000,000 tons with | 4% Cu | equal to 200,000 tons Cu |
| Tilva Mika: | 12,400,000 tons with | 2.9% Cu | equal to 360,000 tons Cu |
| Tilva Roš: | 10,000,000 tons with | 0.8% Cu | equal to 80,000 tons Cu |

Thus, the total copper reserve is around 640,000 tons of metal. About a half of the low-grade ore at Tilva Roš constitutes copper ore; the other half may be marketed as pyritic ore.

### *Majdan Pek, Eastern Serbia*

The large copper deposit of Majdan Pek lies 30 km north of Bor toward the Danube Valley. Thanks to new discoveries it is destined in the near future to double the copper production of the country. An aerial tram, 16 km long, connects it with Dol. Milanovac, a port on the Danube, which here forms the boundary between Jugoslavia and Rumania.

Much older literature is available on this district, as well as a good résumé by Schneiderhöhn (41). This, however, deals only with the pyrite deposits, which have long been known. A later paper by Donath (9) describes for the first time the large copper deposit, which he discovered. Majdan Pek is located in an area characterized by the junction of several major structures and the downward plunge of the east Serbian andesite batholith. This is the same batholith that farther south is the host rock for the Bor deposit. In the Majdan Pek area, however, it narrows to a dike and at other places plunges under an overthrust sheet composed of Tithonian limestone. The latter rides without roots on top of the andesite, and detached slabs are suspended within the igneous rock. The andesitic magma ascended along a deep-reaching overthrust fault with a generally northerly strike. Crystalline schists and older granite were brought in juxtaposition along this fault.

A younger, transverse fissure system trends westerly through the andesite. This rock, as well as the adjacent schists, was subjected to intense shattering and this brought about favorable conditions for hydrothermal alteration and subsequent mineralization.

Chloritic alteration of the dark silicates has propylitized the andesite to a large extent, but this autohydration was not connected with the formation of the ore bodies. It was followed by a hydrothermal cycle of kaolinization, silicification, and pyritization, which affected the andesite and parts of the country rocks. These, as well as the mineralization, were derivatives of the andesite magma.

The mining district itself extends for about 5 miles and is mineralized in various degrees along this distance. Ore deposition took place in several phases and produced three classes of ore deposits:

(a) *Pyrometasomatic deposits of magnetite* that are found at the immediate contact between limestone and andesite, but are of no economic importance.

(b) *Massive bodies of pyrite* of mesothermal origin, which have furnished most of the ore mined so far. They occur along the periphery of the andesite intrusion, either in the igneous rock below overthrust limestone beds or within limestone along its contact with andesite. They occur as irregular ore stringers that extend along fissures into schists forming the hanging wall, and also invade the andesite; some of the ore bodies have many branches. The andesitic country rock is strongly kaolinized. The smaller deposits range from 10,000 to 50,000 tons, but the larger ones contain as much as 700,000 tons.

The sulphur content varies and may be as high as 50 percent. There is also andesitic rock that has not been completely mineralized, yet contains 20 to 40 percent sulphur. Locally, the pyritic ore carries a little sphalerite and chalcopyrite. So far, about one and one-half million tons of pyritic ores, which carried little or no copper, have been mined. Lately production has dropped considerably.

(c) *Impregnations of copper ore in andesite* of mesothermal or epithermal origin are localized along a shattered zone in the interior and deeper portions of the andesite batholith. Underground workings and drill holes disclose a width of several 100 m and a vertical extent of more than 270 m. There are no indications on the lowest level that its bottom has been reached. Intense shattering of the andesite has led to its diffused impregnation by chalcopyrite and strong, contemporaneous silicification. There is a resemblance to the "disseminated copper ores" of the United States, except that at Majdan Pek all copper ores are primary. Chalcopyrite is associated with lesser amounts of pyrite and magnetite, other sulphides are rare. The ore minerals not only impregnate the silicified andesite, but also occur in numerous quartz veins and veinlets that penetrate the country rock. Copper values vary from 0.5 to 3 percent and average about 0.9 percent. In addition, the ore carries 0.5 to 1.5 grams of gold per ton, with an average of 0.6 gram per ton. Proven ore reserves in the main ore body above the level of the valley floor are more than 100 million tons, which contain nearly one million tons of copper, which can be mined in an open pit. The mine is now being opened, and a flotation mill with a daily capacity of 10,000 tons is under construction. It is hoped that in a few years the country's copper output will reach 70,000 tons.

Surface alteration has played a great role in this district. Wherever pyrite outcropped, either in massive bodies or as impregnation zones, it was altered to limonite. The copper content of the pyritic ores was re-deposited as malachite, azurite, and cuprite throughout the oxidized zone, and as chalcocite and covellite in the supergene enrichment zone. Because these secondary ores have been exploited for many centuries, nearly all of them have been mined out above the level of the valley floor. There are, however, several million tons of limonitic ore available that carry 40 to 50 percent iron and which also contains appreciable copper content at some places.

Majdan Pek is the oldest and most renowned mining operation of Jugoslavia. It has been worked for more than 2,000 years, shown by the finding of stone age implements. The Romans operated there until the year 280 A.D., and the Venetians and Ragusians between 1250 and 1450. The major object of these operations was the secondary copper ores found near the surface. Exploitation of the pyritic ores began in 1902 by the Belgian Société des Mines de Cuivre de Majdan Pek.

### *Tetrahedrite Occurrences in Bosnia*

The tetrahedrite deposits are scattered through the territory lying west of Sarajevo. Paleozoic phyllites, Triassic shales and limestones or dolomites make up the country rock. Throughout the area the deposits occur as small

fissure veins carrying tetrahedrite, chalcopyrite and lesser pyrite, cinnabar, stibnite, and other minerals, along with carbonates. The deposits at Maškara and Mračaj, west of Fojnica, used to be the most important ones. Tetrahedrite, containing silver and quicksilver values, was found in pods, rarely in seams and veinlets. The ore ran 2.5 to 15% Cu and 0.5 to 3.7% Hg.

### SILVER AND GOLD

Most of the silver production of the country has originated from the silver content of lead-zinc ores, principally of those from Trepča. The 10 million tons of ore mined there between 1930 and 1950 contained more than one million kilograms of silver.

Gold, on the other hand, has been produced chiefly as a by-product of the Bor copper smelter, and to a small extent from some minor gold deposits. The latter are gold quartz veins in crystalline rocks of northeastern Serbia. Lately, scheelite, in massive form, or finely disseminated, has been found in such quartz veins in the Pek Valley near Blagojev Kamen. Their economic value is unknown. The lead-zinc deposits of Novo Brdo and Leze, which are related to Tertiary andesites, contain appreciable amounts of gold, particularly at Leze.

In former times placer gold was mined, chiefly in Bosnia. The most important gold placers, and the only ones of present economic value, are located in the Pek valley, tributary to the Danube, east of Beograd. Here, the Romans and later the "Saxons" had mined gold.

### ANTIMONY AND ARSENIC.

Occurrences of antimony ores are widespread throughout Jugoslavia and are known in Bosnia, Serbia, and Macedonia as far south as the Greek frontier. The Bosnian deposits are situated west of Sarajevo. Among them are the complex veins of Čemernica near the town of Fojnica. They occur in Paleozoic schists and carry stibnite as the main ore mineral. The most numerous and important deposits are in Serbia where they form a northwesterly belt which can be traced from the Drina district in western Serbia to northeast of Skoplje. In the far south and near the border of Greece are the antimony-arsenic deposits of Alšar, which lies in Macedonia.

Next to lead, zinc, copper and chromite, antimony is an important product in Jugoslavia's export trade. Shortly before World War II Jugoslavia became Europe's largest antimony producer. Before the war the largest producer was the British "Podrinje Consolidated Mines, Ltd." which had its mines at Kostajnik-Krupanj and furnished about 80 percent of the country's production—for instance in 1937, 7250 tons of ore. Later its output was surpassed by that of the German "Montania A.G." which operated at Zajača and Lisa. In 1945 all antimony mines and smelters were nationalized. After the shutdown in 1908 of Alšar, where arsenic was obtained from realgar and auripigment along with rare thallium minerals, the production of arsenic became negligible.

Comprehensive accounts of Jugoslavia's antimony deposits may be found in the booklet entitled "Antimon" by H. Quiring (37, p. 110–111, 127–131), and in a paper by F. Hermann (17). The latter enumerated 18 individual deposits, most of which have no economic significance. They occur in part as replacement bodies in limestone, which are by far the more important, and partly as fissure veins. Most of the deposits have a genetic relationship to late Tertiary igneous activity.

### QUICKSILVER

Quicksilver ore occurrences are common in Jugoslavia, but with a few exceptions are not commercial. The main ore is cinnabar, which is commonly associated with antimony and arsenic ores. This is particularly true for Bosnia. As previously referred to, the Bosnian tetrahedrite deposits contain significant amounts of quicksilver. In Slovenia the lead occurrence at Littai (Litija), east of Ljubljana in the Save Valley, formerly furnished quicksilver as a by-product. Here galena and cinnabar were closely associated. This deposit belongs to the Alpine type of lead-zinc deposits. On the other hand, the cinnabar occurrence on Avala Mountain near Beograd presumably is connected with Tertiary volcanism. It has been out of production for a long period.

Through the annexation of the former Austrian province of Krain the famed quicksilver mine of Idria (Idrija) became a part of Jugoslavia. Its extensive literature of older dates has been summarized by Beyschlag-Krusch-Vogt (1). This deposit lies about 40 km west of Ljubljana in a region characterized by extremely complicated Alpine tectonics. It is located in the immediate vicinity of a large overthrust fault along which beds of Carboniferous and Triassic ages have been pushed on top of Cretaceous limestones. The former have been folded and faulted, creating a belt of shattering, in turn dissected by crushed and brecciated zones. The ore deposit was formed by the impregnation of the crushed rock within one of these zones. Its strike length is 1,500 m and its width ranges from 300 to 600 m. It has been developed to a depth of 350 m. Mineralization is not confined to certain types of rock but is concentrated in the brecciated limestone of the Muschelkalk Formation and in the overlying "Lagerschiefer" or "Skonzaschiefer" of the Wengen Formation (upper Triassic). These beds are crisscrossed by many small fissures that are filled with cinnabar. This network constitutes the main ore body. Locally, the top strata of the so-called "Gailtaler Schiefer," a black shale of Carboniferous age, have been impregnated by cinnabar and native quicksilver to such an extent that they became ore. Due to the silvery sheen created by the globules of quicksilver this formation is called "Silberschiefer" by the miners. Rich ore pockets occasionally are found along larger fissures or at places where the ore beds have been subjected to very strong shattering and dislocation.

The genetic relationship of Idria is still uncertain. It cannot be assigned to the Tertiary volcanism, as no igneous rocks of this period are associated with the deposit.

Idria was discovered around 1470 and operated by the Austrian government from 1580 to 1920. Then it passed into Italian ownership and has belonged to Jugoslavia since 1947. The total production between 1500 and 1951 was 93,200 tons Hg. During 1951, the output was 126,600 tons of ore with a grade of 0.45 percent Hg yielding 505 tons of metallic quicksilver.

### MOLYBDENUM

In several parts of Jugoslavia small occurrences of molybdenum are found in quartz veins, aplites and masses of skarn. In this group belongs the small deposit at Stari Glog near Vranje in southeastern Serbia. Here molybdenite is contained in quartz veins within granite and represents the normal deep-seated type.

The large, but low grade, deposit of Mačkatica is located in the same district of southeastern Serbia as Stari Glog between the Morava Valley and the Bulgarian frontier. A large plant built by the Germans during World War II stands near the village of Surdulica, but never reached production.

Literature about this deposit is nonexistent, but some unpublished reports are available. According to these, geological conditions are as follows:

The ore district is made up of crystalline schists invaded by stocks of granite, granodiorite and dacite. The granodioritic plutonic phase and the dacite eruptions are closely related, but the mineralization is connected only with the Tertiary dacite stock, which has a surface area of about 300 square kilometers. It is composed of several eruptions of differing ages, but only the oldest of these is said to be mineralized. The ore was deposited as large impregnations in dacitic rocks and also in the adjacent mica-schist. These rocks have been silicified to a large extent. Silicification spread from a network of small quartz veinlets that criss-cross the dacite. The quartz veinlets contain fine grained molybdenite and a little pyrite. Thus the ore body is a large stockwork, which resembles that of Climax.

On the upper levels the dacite is sericitized rather than silicified, but the sericitized portions at depth grade into the regular ore body. Mineralization is related to fissure systems that cut the mineralized rocks and the best ore is found in those areas where fissuring is most intense. Away from these areas the molybdenum content gradually diminishes.

According to Cissarz (3, p. 52) Mačkatica is an unusual example of a molybdenum deposit connected with shallow igneous activity, yet is not of pneumatolytic, but of hydrothermal origin. It belongs to the Tertiary igneous cycle, which also embraces most of the lead, zinc, copper and antimony deposits of the country.

Ore reserves are large and are believed to exceed 100 million tons. The grade, however, is quite low and averages only 0.08 percent Mo which is about one-fourth of the grade prevailing at Climax. It is true that the ore body contains richer parts, but it is not economic to mine them separately. The plan was to produce 2,500 tons of ore per day, but it remains to be seen whether this can be accomplished.

### CHROMIUM

Jugoslavia is richer in chromium deposits than any other country in Europe. During both world wars its deposits contributed most of the chromium needed by Germany and its allies. Prior to World War II a British company, the "Allatini Mines," contributed greatly to the country's production through mining operations near Skoplje, Macedonia. The most valuable publication, dated 1951, is a comprehensive treatise by G. Hiessleitner (20). In 1930 M. Donath (10) wrote a detailed paper on the largest deposit of Jugoslavia that is in the Ljuboten district of Macedonia.

Jugoslavia has more basic and ultra-basic igneous rocks than any other part of Europe most of which are peridotites largely altered to serpentine. These form belts, elongated northwesterly, which extend from the Save River on the north through Bosnia, western and southern Serbia, and Macedonia deeply into Greece; in a westerly direction they reach into Albania. Individual serpentine areas are as much as 1,000 square km in size. There is no direct relationship, however, between the size of a serpentine stock and the extent of the chromite enrichments within it. On the contrary, exploration programs so far have shown that chromite deposits favor the smaller stocks and that the larger serpentine areas are practically barren.

The petrographic and chemical features of the peridotites vary. Dunitic, as well as harzburgitic and lherzolitic types are found. Locally, pyroxenes may become major constituents of the peridotites. At most places the serpentine is crossed by dikes of pyroxenite and gabbro. Such dikes have a coarse-grained or even pegmatitic texture, and are believed to be younger offshoots of the basic magma. Valuable concentrations of chromite are found predominantly in the extremely basic, that is dunitic, members of the series. The richness of an individual stock, therefore, is more dependent on its chemical composition than its size. In this respect the Ljuboten District is a good example in view of the ultra-basic type of rock.

The most important chromite-bearing serpentine stocks occur in southern Serbia and adjoining Macedonia. Here they are grouped in elongated strips or lines flanking the Pelagonic basement complex of schistose rocks, and also along the west rim of the Rhodope Mountains. The western edge of the Wardar Zone, in particular, contains a chain of serpentine intrusions carrying valuable chromite deposits.

All Balkan chromite deposits have been intensely dislocated. As a result of folding and faulting the chromite-bearing serpentine is intermingled with gabbro and diabase, with Flysch sediments, Triassic and Cretaceous limestones, and various Paleozoic shales. Where chromite bodies are involved in tectonic movements their edges are cut off and they are squeezed and rolled so that finally a high-grade ore body with sharply defined structural contacts emerges.

The age of the chromite-bearing serpentines is still in debate. Some authors, for instance Kossmat, place them into the Mesozoic, particularly in the Triassic or Jurassic. Hiessleitner assumes a late Paleozoic age. According to Cissarz (3, p. 40) Jugoslavian geologists maintain that the

chromite-bearing serpentines of southern Serbia and Macedonia belong to the early Paleozoic era. Their predominantly structural contacts militate against definite age determinations and it is possible, too, that serpentine intrusions were not confined to a single era or period, as recently pointed out by Kober (49, p. 10 and 37).

Because chromite was segregated through differentiation in solid or fluid phases the ore is more or less diluted by serpentine inclusions. In Jugoslavian mining practice, therefore, three grades of ore are distinguished: first grade, containing more than 48% $Cr_2O_3$; second grade, with 48 to 42% $Cr_2O_3$; third grade, with less than 42% $Cr_2O_3$.

Jugoslavia's more important chromium mining districts are described below.

*Raduša or Ljuboten District, Macedonia.*—This deposit lies 20 to 30 km northwest of Skoplje on the south side of the 2500 m high Ljuboten Range, between the valleys of the Wardar on the west and the Lepenac on the east. The serpentine stock is 16 km long, 3 to 6 km wide and embraces 65 sq. km. In spite of its small size it contains the richest chromite district of the Balkan Peninsula. Structurally, it is a unit of the Wardar Zone and has been block-faulted. The country rock is mostly dunite altered to serpentine. This stock shows a remarkable vertical zoning, the basal zone rests on phyllite and is richest in chromite, which occurs in the form of irregular lenses of massive ore. It is overlain by a zone of serpentine that contains little or no ore, and is several 100 m thick. The highest zone is also rich in chromite, which occurs as impregnated ore in the shape of irregular layers, some of which are several hundred meters long.

Several characteristic types of texture are found in this district, a fine-grained, massive ore, a coarsely impregnated ore, a spherulitic type made up of corroded chromite grains arranged in balls (so-called leopard ore), and a layered type where layers of pure chromite alternate with nearly barren streaks of serpentine. Similar textures can be seen at other chromite deposits and they are the result of depositional and structural processes. The massive type mostly is found immediately at the basal contact of the serpentine stock, whereas the spherulitic type occurs in the interior of the stock in its lower portion. Ores with banded texture are seen well in the interior of the stock, and the coarsely impregnated type is in a zone closest to the hanging wall.

The most important mines of this district are:

(a) *Nada Mine,* the largest chromite mine of the country. It yields chiefly first- and second-grade ores and to a lesser extent third-grade ore. The maximum depth is 250 m and total production is more than 500,000 tons of chromite ore. This tonnage makes it one of the largest chrome mines of the world.

(b) *Oraša Mine,* which used to be the largest mine of the country, is more than 40 years old. It has produced nearly 500,000 tons of predominantly first- and second-grade ores. Today, it is largely exhausted.

Both of these mines are located only 100 to 200 m above the base of the serpentine stock. All the other mines of the district are small schlieren, each

of which contains between 10,000 and 20,000 tons of ore. These are mostly disseminated ores of the third grade, the tenor of which may drop to 30%, or even to 20% $Cr_2O_3$. They are milled at the Djorče Petrov plant, which lies 5 km distant from Skoplje, and yields concentrates with about 52% $Cr_2O_3$.

*Bresovica District in the Upper Lepenac Valley of Macedonia.*—This district is located on the north side of the Ljuboten Range on the upper Lepenac River, a tributary of the Wardar River. A railroad, 30 km long, connects it with Kačanik, a station on the main line connecting Beograd with Kosovska Mitrovica and Skoplje. All the deposits are localized in small blocks of serpentinized peridotite, which are underlain and framed by schists. The largest of these is about 4 sq. km, the smallest ½ sq. km in area. The country rock is mostly dunite, parts of which have not been serpentinized. Other portions carry abundant pyroxenes. Through extreme differentiation, segregations of pyroxenite and anorthosite have been formed in some places.

Chromite ores are distributed as schlieren and pockets irregularly through all of the ultra-basic rocks. The ore bodies do not have definite walls and merge into the country rocks. Massive ores are uncommon. Their elevations above sea level range from 800 to 2,000 m. The largest deposit is that of Jezerina-Ostrovica, which was mined at altitudes from 1,700 to 1,900 m. It consisted of a series of adjacent schlieren formed near the base of the peridotite, and furnished much massive ore. Its total production exceeded 150,000 tons; today, the deposit is largely exhausted. The other eight deposits are much smaller and furnished mostly disseminated ores of third grade.

*Djakovica District, Southern Serbia.*—This deposit lies northwest of Prizren, close to the border between Jugoslavia and Albania. The serpentine stock has a maximum length of 22 km and an average width of 4 km. Its area within Jugoslavia is about 85 sq. km, but it extends far into Albania so that in this country an area of more than 1,200 sq. km is covered with peridotite, serpentine and diabase. The stock is part of the Merdita thrust plate and its limits are mostly determined by structure.

The serpentine at Djakovica is somewhat more acid in composition than that of the other districts. In addition to dunitic phases there is a variety rich in pyroxene. Accessory chromite is widely diffused through all of these rocks. There are more than 65 outcrops of chromite-bearing rock of which Deva is the most noteworthy. It produces mainly second-grade ores, which occur in a belt more than 200 m long and 120 m wide, with thicknesses of ore bodies ranging from 0.5 to 5 m.

During World War II the Italians conducted some mining in the Djakovica district, at Deva; however, production began only in 1949. Since that time its output has increased to make this district the second largest one of the country.

Between Djakovica and the district seat of Priština, the mining districts of Orahovac and Drenica are now in development. Fairly large serpentine stocks here contain chromite concentrations.

*Lojane near Kumanovo, Macedonia.*—Lojane lies about 30 km northeast of Skoplje and is connected by a narrow gauge railroad, 7 km long, with Tabanovci, a point on the Niš-Skoplje line. Chromite-bearing serpentine

lenses are arranged en echelon in a northwesterly direction. Geologically, it is remarkable that here serpentine is associated with Mesozoic limestone, as well as andesite and younger granites. These igneous rocks pierce the serpentine with numerous apophyses. Within the serpentine area of the mining district which is barely 2 sq. km in size, more than 100 granite apophyses perforate the serpentine like a sieve. Thus, it is possible to find chromite in direct contact with granite. The granite intrusions brought about the formation of uvarovite, chrome-diopside, kämmererite (a chromium-bearing chlorite) and phlogopite. In the Antoinette mine andesite has intruded the serpentine and led to the deposition of epithermal stibnite and realgar.

The main ore body is lenticular and is bordered on all sides by faults. In all, this district has produced more than 80,000 tone of chromite ore, consisting of massive and disseminated ores in about equal proportions. The principal mine is approaching depletion.

*Rabrovo near Valandovo, Macedonia.*—This is the most southerly occurrence, as it lies close to the border of Greece. It is 16 km distant from Mirovci, a station on the Skoplje-Saloniki railroad line. Owing to its position along the eastern edge of the Wardar Zone this district has a complicated structure. At every place the serpentine is bounded by structural contacts; it occurs as a block between Paleozoic and Mesozoic rocks. It is of quite small size and contains two mineralized zones, one carrying massive ore and the other disseminated ore. Bodies of massive ore occur as steeply-dipping, elongated lenses due to tectonic influences, and are up to 6 m thick. Ore reserves are small, but of excellent quality. First-grade ore runs 52 to 54% $Cr_2O_3$, second-grade ore about 44%. At this time no mining is in progress.

After World War II the output of chromium ore dropped from a 1942 production of 100,000 tons to about 10,000 tons, but in 1952 reached 107,000 tons.

## IRON

The iron ore reserves of Jugoslavia are not large, but of sufficient size to supply domestic needs with an exportable surplus. Ljubija and Vareš are the principal deposits. Of wide distribution are marine-sedimentary iron ore deposits such as those in the Šumadija region which lies south of Beograd between Kragujevac and Arandjelovac. They belong in the lower Cretaceous and some of them are of the residual type. Others are low-grade, oolitic limonites, which were formed by the decomposition of serpentine and redeposition of its iron, chromium and nickel contents (Cissarz 3, p. 54). In connection with the description of the pyritic ore bodies of Majdan Pek reference already has been made to their secondary limonite zones.

Summaries of the Jugoslavian iron ore deposits may be found in publications by Katzer (28), Friedensburg (13) and Hermann (18).

*Ljubija, Northwest Bosnia.*—These occurrences lie 10 to 15 km southwest of the town of Prijedor. The entire region has abundant iron ore and Ljubija is the center of mining operations that have been carried on since 1917. Since that time Ljubija has played an important role in the iron ore production of the country. All mining is done in open pits of which the largest opera-

tion is the Javorik pit near Ljubija; other mines lie about 5 km farther south near Kozin.

The iron ore deposits occur in a series of Paleozoic sandstones and argillaceous shales, which at different levels contain limestone beds and lenses. The beds have been subjected to folding of two different periods, the older probably being of Permian, the other of Tertiary age (Dinaric system).

Great irregularity of form characterizes the deposits. A few of them are fissure fillings, others are tabular, but the majority occur as irregular stocks and lenses. In nearly all cases their limits are structural. Some of them lie close together, others are separated by large masses of shale. The size of individual ore bodies also varies to a great extent. In addition to compact bodies of ore, there are stockworks in shale that are made up of thin siderite and limonite veinlets forming an intricate pattern. Most of the ore bodies are suspended in country rock, that is, they have no roots. Only at two places do they extend to depths reaching 150 m and the majority of the smaller deposits have vertical dimensions of less than 50 m.

The content of the crude ores is rather low. The best class of ore consists of limonite with about 40% Fe, 2% Mn and 10% $SiO_2$. Sideritic ore averages 35 to 36% Fe and 2% Mn. The phosphorus content of both types is between 0.2 and 0.3 percent. The thickness of the ore bodies varies greatly and reaches 20 m in the case of siderite bodies. That of the limonitic surface deposits is much larger.

The genesis of these deposits is difficult to understand. Katzer's original conception (25, p. 507) of a predominantly hydrothermal-metasomatic origin is not acceptable, as replacement of limestone is known to play a subordinate role only. The largest and most important ore bodies do not occur in limestone. According to Noeth, they are not of uniform origin. Some of them, namely the economically important ones, are hydrothermal fissure fillings. They have a considerable vertical extent and contain siderite with galena and other sulphides; their country rock is mostly shale. Their genesis is believed to be connected with Permian igneous activity. Another group of the deposits in this district are of sedimentary origin and probably of Tertiary age. They contain limonite, have a limited vertical extent and form beds deposited at low angles. On the other hand, it may be suggested that the entire mineralization at Ljubija belongs in the younger metallogenetic province of the eastern Alps, which is of great magnitude and embraces the famous siderite deposit of the "Erzberg" in Styria.

*Vareš, Central Bosnia.*—These deposits lie about 40 km northwest of Sarajevo and belong to the Triassic. Werfener shales of lower Triassic are overlain by limestones and dolomites of the middle Triassic. The ore-bearing horizon occurs in the lower division of the latter. The iron ores are interbedded with these Triassic sediments and consist of siderite in the lower part and predominantly hematite in the upper section.

The structure of this district is complicated. The principal element is a large overthrust along which Triassic beds have been pushed over Liassic and Cretaceous sediments.

Mining operations are carried on in three sub-districts: Smreka-Droškovac,

which is the largest and yields siderite and hematite; Pržici, yielding hematite only; and Brezik, yielding siderite, hematite, and limonite. There are also several smaller deposits. Before World War II, the tenors of the ores were as follows:

| | |
|---|---|
| Hematite: | about 60% Fe and 0.5% Mn |
| Limonite: | about 45% Fe and 2.5% Mn |
| Siderite: | about 40% Fe and 4% Mn |

The silica content varies between 6 percent and 9 percent and is highest in sideritic ore. Formerly only oxidized ore was mined in open pits. Today mining operations increasingly deal with the production of siderite which, quantitatively, is the most important ore.

Katzer (28) believed these deposits to be of epigenetic-metasomatic origin and that they were formed through the replacement of limestone by iron-bearing solutions. More recent studies do not support his conception, because there are no indications that limestone has been replaced by iron ore, and the latter shows definite stratification. It is believed now that the deposits are of marine, sedimentary origin, although it is assumed, in accordance with Katzer's views, that the ore-bearing solutions were derived from basic magmas of Triassic volcanism. It is assumed that iron contained in submarine, melaphyric lava flows was transported soon after they congealed in the form of hot exhalations or solutions into the Triassic sea. Here, the iron was precipitated either in the form of hematite or as siderite (3, p. 44, 53–54).

The iron ore production of Jugoslavia 90 percent of which came from the two large deposits described in the foregoing was 676,000 tons in 1952 and a production of 1.5 million tons is planned for the future.

Iron ore reserves in Bosnia and Herzegovina are estimated at more than 100 million tons.

The two largest steel mills are located at Zenica and Sisak, respectively. In 1952 pig iron production was 273,000 tons and steel 442,000 tons.

### MANGANESE

In contrast with its iron resources, the manganese ore reserves of Jugoslavia are meager, the occurrences are small and the quality of the ores is low because of high silica and iron. Genetically, two types may be distinguished—marine, sedimentary occurrences and residual deposits. To the first group belongs the largest and best known manganese district of the country, namely Čevljanovic in Bosnia. Residual deposits are scattered over the entire country, but most of them are small. Possibly an occurrence at Cer near Kičevo, which is now in the development stage, is of the residual type.

The manganese ore production of Jugoslavia before World War II was only a few thousand tons. In 1952, 12,687 tons were produced.

### BAUXITE

Jugoslavia, France, and Hungary are the large bauxite-producing countries of Europe. Jugoslavia owes this position to its abundance of calcareous

bauxite deposits within the Dinaric coastal zone of the eastern Adriatic, the Karst. Here, a calcareous land area underwent karst erosion and under semi-arid climatic conditions bauxite was formed in residual deposits. Contrary to most other Jugoslavian ore deposits the bauxite occurrences have been well described in geologic literature. Recent publications are by Friedensburg (13) and Quitzow (39) and above all the monograph of De Weisse (5).

The Jugoslavia deposits occur as fillings of depressions on the surface of the Karst. In most cases they rest on limestone bedrock. Although they may vary in other respects, two morphological features are common to all of

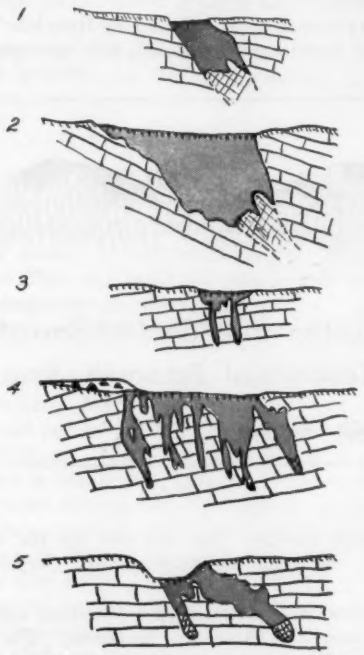


FIG. 2. Profiles of bauxite deposits in Herzegovina.

them—the irregularity of the footwall and the regularity of the hanging wall. Two basic forms may be distinguished:

*Pods, Pockets, Chambers and Pipes in Limestone* (Fig. 2).—Commonly, pillars or pyramids of limestone stand within these deposits and usually reach from their footwall through the entire thickness of ore to the surface. This feature makes it difficult to estimate the tonnage contained in an ore body. The size of deposits of this type varies considerably. The smallest have a diameter of a few meters only and contain a few hundred tons of ore; the other extreme is represented by bodies containing more than 200,000 tons of bauxite.

The ore bodies always are grouped; single occurrences are unknown. Most of the country's bauxite deposits are of this type.

*Vein-like Fillings of Openings Along Bedding Planes* (Fig. 3).—These deposits commonly occur as long, thin "veins" with steep or vertical dips. Locally, they may swell from a width of a few centimeters to several meters. They also vary in their vertical extent. For instance, in the Bosanska Krupa district the ore wedges out at a maximum depth of 60 m, whereas at Kalun near Drniš workings extend to about 400 m still in ore. The bauxite is generally pisolitic and consists of hydrargillite (gibbsite) and boehmite; diaspore is of no significance.

The deposits were formed at periods ranging from late Triassic to Miocene. The three principal bauxite horizons fall into the upper Triassic, upper

FIG. 3.

Cretaceous and middle Eocene. The last two are the most important and have given rise to the trade designations of "Cretaceous bauxite" and "Tertiary bauxite."

The Cretaceous bauxites rest on Rudist limestone and have a capping of Cosina beds with overlying Alveolina limestone. The Tertiary bauxites occur within the Alveolina limestone and their cap rocks are either calcareous conglomerates of the Promina formation, or calcareous sandstones. Most of the commercial bauxite deposits, however, were formed during the middle Eocene within the Dinaric coastal belt. Accordingly, these Tertiary bauxites are confined to a narrow strip running along the Adriatic from Istria through Dalmatia into Herzegovina.

The Jugoslavian bauxite deposits as a whole are distributed through the entire Karst Region, beginning in Istria in the north and extending through Dalmatia, Bosnia and Herzegovina into Montenegro in the south. In this large territory the reserves of visible ore are estimated at 20 million tons. About half of this tonnage has been sampled and analyzed.

The deposits of Istria have yielded about 5 million tons of ore, of which the red bauxite, the better grade, averages 57% $Al_2O_3$, 1.6% $SiO_2$, 25% $Fe_2O_3$, 3.7% $TiO_2$. Those of Drniš, Dalmatia, have yielded 4 million tons of somewhat lower grade, and less than 1% $SiO_2$. The Galiči deposits of Imotski, Dalmatia, contain about 1.5 million tons of higher silica ore. The unusual ores of Bosanska Krupa, Bihač, in Bosnia, are in a fissure 25 km long of which 15 km is ore, averaging 1 m in width. This bauxite carries 62–66% $Al_2O_3$, 1–3.6% $SiO_2$, 11–21% $Fe_2O_3$, 2.8% $TiO_2$. The rich Herzegovina deposits with reserves of 8 million tons of ore average around 58% $Al_2O_3$, 1.4% $SiO_2$, 25% $Fe_2O_3$, and 2.7% $TiO_2$. Other deposits are Nikšić, Bar, and Ulcinj in Montenegro.

The bauxite production of Jugoslavia has increased from 173,000 tons in 1933 to 756,000 tons in 1938. In 1952 the production was 577,000 tons.

## NON-METALLIC MINERALS

Among the non-metallic minerals magnesite and asbestos are of importance.

*Magnesite.*—In view of the wide distribution of serpentine it is not surprising that magnesite is found at many places connected with this rock. The serpentine stocks of Serbia, in particular, are rich in magnesite. Most of these occurrences, however, are small and contain only a few thousand tons. Goleš is the largest magnesite operation of the country. Ore reserves amount to about 4 million tons and nearly the entire production is burned in modern furnaces.

The magnesite veins are very irregular, both in strike and in dip. They occupy fissures with many branches that abruptly end and reappear. The widths of the veins are just as variable, as they swell and diminish in thickness within short distances. Widths of 20 m and more are not uncommon. The quality of the ore is changeable; high-grade shoots give way to parts so high in silica as to render the magnesite unfit for the market. The serpentine country rock generally is much altered in proximity to the veins.

Most of the magnesite bearing fissures are of tectonic origin. According to Hiessleitner (21) they are of Tertiary age. Their vertical extent is considerable and is governed by the relief of the surface as it existed when they were formed. As Stappenbeck (46) pointed out in connection with the Vrutci deposit, most of the magnesite was formed by hydrothermal alteration of serpentine through hot solutions carrying carbon dioxide. In the course of more recent investigations of Silesian magnesites, Spangenberg (45) concluded that the magnesite was formed by ascending, hydrothermal solutions.

Large ore reserves assure the magnesite industry of Jugoslavia a great future. Before World War II the annual production of crude magnesite was around 40,000 tons and reached 89,900 in 1951.

*Asbestos.*—Prior to 1946 Jugoslavia produced no asbestos. Now chrysotile-asbestos has been found at many places within serpentine areas, although of inferior quality due to short fibers and low concentration. Deposits are

mined at Korlaće and Belci. The former occurs at the contact between serpentine and an intrusive Tertiary andesite, and the richest fiber lies close to the contact. The length of the fibers is 1 to 10 mm, and mine-run rock contains only 2–3 percent asbestos, which is hand sorted to 4–5 percent milling product.

## CONCLUSIONS

From the foregoing discussions it may be seen that Jugoslavia is endowed with many types of mineral deposits. The greater part of the mineralization belongs to a metallographic province of Tertiary volcanism and intrusions, and this is particularly true for the deposits of lead, zinc, copper, antimony, arsenic and molybdenum. On the other hand, there is a serpentine province rich in deposits of chromite and magnesite, and to a lesser extent contains occurrences of asbestos.

In addition to these two well-defined geological types, the country has various mineral deposits of magmatic derivation, the geological position of which is still uncertain. These are located mostly in Bosnia.

The sedimentary cycle is represented by marine, sedimentary deposits of iron and manganese, as well as by widespread occurrences of bauxite that are of residual origin.

No doubt, the number of mineral deposits that have been discovered so far, or are now in production, will increase considerably with progressive geological exploration of the country. Above all, there is a great need for up-to-date descriptions of individual districts that later could be assembled in a comprehensive treatise of the country's economic geology.

## ACKNOWLEDGMENTS

The writer is greatly indebted to Mr. Walter H. Koch of Salt Lake City, Utah, who translated the German manuscript into English, and to Professor Charles H. Behre, Jr. of Columbia University, New York, for his valuable criticisms of the translation.

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WESTERN GERMANY,
*Oct. 1, 1953.*

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# ORE CONTROLS AT THE GUADALUPE MINE, NUEVO LEON, MEXICO [1]

F. B. WHITING

ABSTRACT

At the Guadalupe mine, Nuevo Leon, Mexico, a complex of stocks and dikes of porphyritic Laramide (?) igneous rocks has intruded a dome of Upper and Lower Cretaceous sediments, predominantly gray limestone and black limy shale. Faults, some flat and some moderately-dipping, cut both sediments and igneous rocks.

The best ore shoots occur along the lines of intersection of flat faults with vertical dikes in shale, where pencil-shaped breccia zones were formed in which barite, sphalerite, and silver-bearing galena were deposited.

As the mineralization proceeded almost exclusively by open-space filling, the size and openness of each breccia zone determined the size and grade of that ore shoot. As most of the productive faults have closed outcrop lines around the hills, the greatest possible length of each shoot, and consequently an upper limit to its potential tonnage, can be found by projecting the dike-fault intersection line through the hill from the present exposed face to the outcrop point.

## INTRODUCTION

THE Guadalupe mine is situated 1½ miles east of the settlement of L'Iguana, about 23 miles southeast of Lampazos in the province of Nuevo Leon, northern Mexico. The mine is idle, and, according to local people, has not been operated since 1919. Ore from several diggings was treated in a small mill at L'Iguana. Silver-bearing galena was recovered, and sphalerite and barite were discarded with the gangue.

Information presented here was obtained by G. F. Weaton, Jr., and the writer during a three-week examination in February, 1952, on behalf of the St. Joseph Lead Company. Thanks are due to Dr. John S. Brown and Dr. E. L. Ohle for criticism of this report, and to officials of the Company for permission to have it published.

## REGIONAL SETTING

The eastern part of the Sierra Madre Oriental is made up of broad folds that trend north-northwest. The mine is situated at the edge of Mexico's Gulf Coastal Plain where an elongated dome, the most easterly representative of those folds, brings to the surface a section of Lower Cretaceous and younger rocks. The dome has a core of intrusive rocks that are part of the general suite of Laramide intrusives so widespread in the Cordilleran area.

On the basis of sequence and lithology the limestones at the base of the local section are considered by the writer to correspond to the upper part of

[1] Presented before the Society of Economic Geologists, Toronto Meeting, November, 1953.

FIG. 1. Surface geology

the Washita-Fredericksburg divisions of the Lower Cretaceous Comanche series. The overlying shaly beds are thought to be the Eagle Ford formation, the lowest beds of the Upper Cretaceous sediments. As far as is known, the contact here between Upper and Lower Cretaceous beds is conformable.

## LOCAL GEOLOGY

The distribution of the sediments and intrusive rocks around the central Guadalupe workings is shown in Figure 1.

At the base of the local section of sediments is a gray, thick-bedded, slightly shaly limestone that is at least 300 feet thick. It occupies most of the floors of the broad valleys. Above the limestone, and accordingly exposed midway up the sides of the hills, is about 60 feet of thinly-interbedded chert and gray shaly limestone. Above this, forming the ridge crests, is at least 400 feet of black limy shale. No fossils were found in any of these rocks. Outside of the mine area, underlying the broad flats that surround the dome, is a thick gray fossiliferous limestone that is part of the Upper Cretaceous beds.

The sediments are intruded by many dikes, sills, and irregular masses of porphyritic igneous rocks close to andesite in composition. These differ widely in color and texture. In some bodies the phenocrysts are hornblende, in others feldspar, and in a few, biotite. Many bodies contain both hornblende and feldspar phenocrysts in varying proportions, the crystals ranging up to one inch in largest dimension. All the igneous rocks appear to be phases of one magma, and all seem to date from the same general time of intrusion.

The shapes of the igneous bodies vary with the enclosing rock. In the valley bottoms where limestone is intruded, the igneous masses tend to form large bodies irregular in outline. High on the ridges, cutting through the black limy shale, they tend to occur as dikes and sills a few feet thick. Most of the dikes are nearly vertical and extend north 40° west. They have straight walls with sharp contacts and, in places, fine-grained margins. Some are uniform in thickness and attitude for several hundred feet; others terminate abruptly, split, change direction, or become sills.

Here and there, blocks of highly contorted and partly metamorphosed sediments are enclosed by the larger igneous bodies. No evidence of the conversion of sediments to porphyritic rock was found. The metamorphism does not obscure the original character of the sediments. Along some dikes, the black shale is converted to a hornfels. Elsewhere, the color of the shale has been changed, along a multitude of nearly horizontal cracks, from black to gray or greenish-gray. Small areas of limestone are clear green in color. Near large bodies of intrusive rock the limestone commonly is metamorphosed to a tactite composed of fine-grained calcite, coarse red and green garnets, wollastonite, and actinolite.

In the mine area the attitude of the sediments ranges between horizontal and a dip of 20° to the south.

All the rocks of the area are cut by a set of faults, most of which dip almost parallel to the dip of the sediments. Figure 1 shows the more prominent of these faults. Many others probably exist but were not noticed owing

to the parallelism of the bedding partings with the fault outcrops, and owing to the lack of outcrops over large parts of the hillsides. Another system of faults, similar in character but steeper in dip, extends northwards along the west edge of the mine area. The dip of these faults is generally about 35° to the east. The movements which have taken place on these faults could not be determined. Some contacts were observed to be offset as much as 200 feet, however. Slickensides are present in a few places: they extend east and west.

The mine is situated in an area where the regional faults run a little to the west of north and dip east. The slight southward dip of the main Guadalupe fault is, therefore, at variance with the regional pattern and may represent merely a slight warping of a fault which, if it were followed far enough, might be found to be an overthrust from the east.

As many of the faults are relatively flat, they tend to outcrop roughly parallel to the contours of the hills, and many no doubt encircle the hills completely.

## ORE HABIT

Ore is found within the fault zones and nowhere else. Three types of deposits are recognized, the differences between them resulting from the differing responses of the various host rocks to the faulting. A fault in shale tends to be either one thin, highly-sheared and slabby zone or a set of such zones stacked one above the other, each perhaps a foot thick and separated from adjoining ones by one- or two-foot sections of massive, unsheared rock. A fault in limestone tends to be a single, slightly wavy, partly open crack. A fault that cuts igneous rock tends to produce either a blocky open breccia or, if the movement were concentrated within a few inches, a highly granulated mass.

These differences in the characteristics of the fault zones from place to place are reflected in the ore types commonly found here within each host rock.

Where the faults are completely within the black limy shale, they carry only small amounts of the barite, galena, and sphalerite, and have not yielded more than a few tons of hand-picked ore. Traces of the sulphides can be found almost everywhere along every fault, but this type of deposit is generally without economic importance.

In places in the shales, and commonly in the limestone, the faults contain massive lenses of coarsely-bladed barite, up to 2½ feet thick. These lenses contain pockets and seams of galena and sphalerite. They are found in great abundance in the valleys and on the lower parts of the hillsides, where limestone is the most widespread country rock. Many have been mined, completely or in part. The lenses are mostly less than one foot thick and, as far as could be determined, have not been found to extend more than 200 feet along the strike or dip. They seem to be scattered at random along the faults, with large segments of barren fault between them.

The best ore bodies occur where the faults have brecciated thick sections of the dikes. Along the line of intersection of each dike with each flat fault

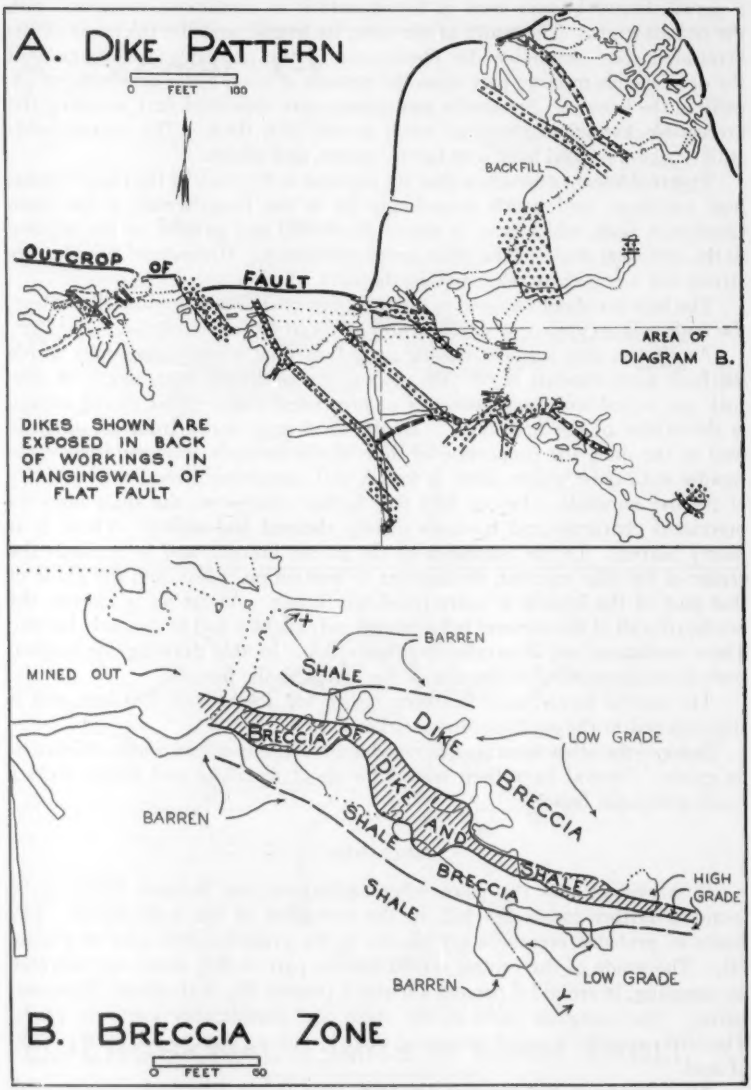


FIG. 2. A. Dike pattern. B. Breccia zone.

a pencil-shaped breccia zone is found, which is commonly cemented with the ore minerals. The width of the dike, its length, and the thickness of the brecciated zone determine the dimensions of the ore body. The grade of the ore depends in large part upon the amount of open space developed originally in the breccia. Sphalerite and galena were deposited first, covering the breccia blocks with coatings as much as one inch thick. The excess interstitial space was filled later with barite, quartz, and calcite.

Figure 2A shows the dikes that are exposed in the back of the main Guadalupe workings, and which accordingly lie in the hangingwall of the main Guadalupe fault, which here is almost horizontal and parallel to the bedding in the enclosing shale. The dikes trend northwest. Mineralized breccias are strung out along these dikes within the fault zone.

The best ore shoot exposed in the workings is shown in Figure 2B. Here, the fault split to enclose a segment of dike up to 12 feet thick.

As shown, this segment of dike, which is now a brecciated mass inside the fault zone, extends N 65° W. Along its southwest edge, blocks of dike rock are mixed with large amounts of brecciated shale. This mixed section is the center of the ore shoot. To the southwest, away from the original wall of the dike, the proportion of dike blocks to shale fragments decreases rapidly until only broken shale is found, still containing a moderate quantity of the ore minerals. Ten to fifty feet farther southwest, the shale loses its brecciated character and becomes merely sheared and slabby. There it is nearly barren. To the northeast of the mixed breccia, and so towards the center of the dike segment, the amount of brecciation is less, and the grade of that part of the breccia is correspondingly lower. As far as is known, the northeast wall of the segment is brecciated only slightly and so is nearly barren. These variations are illustrated in Figure 3A. In this drawing the vertical scale is exaggerated, as is the size of the blocks in the breccia.

The central mixed zone has been mined for a length of 390 feet, and is still exposed in the southeasternmost heading.

None of the other breccias examined approach this one in width, thickness, or grade. Several have been mined for short distances and might yield a small additional tonnage.

## CONCLUSION

It is evident that the place where additional ore is most likely to be found is farther inside the hill, in the extension of the main shoot. The limits of probable ore there are shown in the cross-hatched area of Figure 3B. The grade of the central mixed-breccia part of this shoot, as indicated by sampling, is around 4 percent Pb and 6 percent Zn, with about 25 percent barite. The marginal parts of the shoot are considerably lower in grade. The silver content is small, not more than 1½ ounces per ton for each percent of lead.

An estimate of the tonnage available from other dike intersections with the main fault is difficult to make because of the patchy nature of the mineralization, and the tendency of the dikes to split, bend, or end abruptly. In

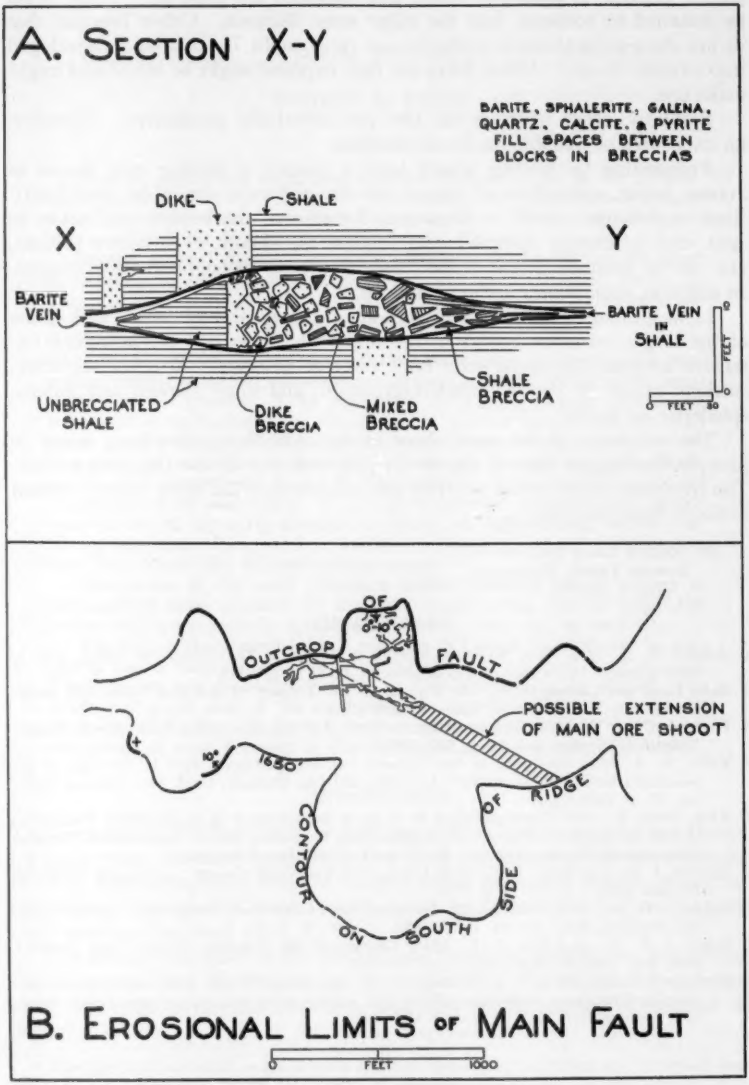


FIG. 3. A. Section x-y. B. Erosional limits of main fault.

places, breccias of moderate grade and thickness are exposed. These could be assumed to continue into the ridge some distance. Other breccias that do not show mineralization at the present faces might, if explored, be developed into minable shoots. Other dikes not now exposed might be found and might make ore.

Similarly, other faults in the area are potentially productive. However, no exposures of minable grade are known.

Prospecting by drilling would have a chance of finding new shoots in known faults, extensions of known shoots, and new shoots in new faults. Such exploration would be hazardous because of the tendency of dikes to split, end, or change direction, and because the shoots, even where present, are not of uniform grade, width, and thickness throughout their lengths. In addition, these shoots are generally small.

It was thought that the intersection of strong sets of faults with some of the larger intrusive bodies in the floors of the valleys might afford extensive breccias that could offer hope of large reserves. None of the intersections examined showed much brecciation, and none showed any galena, sphalerite, or barite.

The extension of the main shoot in the main fault, therefore, seems to provide the biggest part of the predictable reserves of the Guadalupe mine. The combined effects of ore controls and erosion have set fairly closely defined limits to these reserves.

St. Joseph Lead Co.,
Bonne Terre, Missouri,
*Dec. 1, 1953*

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# PEGMATITIC LITHIUM DEPOSITS IN CANADA[1]

ROBERT B. ROWE

ABSTRACT

Granitic pegmatites containing lithium minerals occur in the Yellowknife-Beaulieu district, Northwest Territories; the Cat Lake-Winnipeg River, the Herb Lake, and East Braintree-West Hawk Lake districts, Manitoba; and the Preissac-Lacorne district, Quebec.

Several general characteristics are exhibited: 1. The pegmatites occur in medium- to high-grade metamorphic rocks or in plutonic rocks. 2. They are associated spatially and perhaps genetically with bodies of granite that contain 20 to 40 percent microcline and 20 to 40 percent albite or oligoclase. 3. They are marginal and exterior pegmatites. 4. In districts where regional zonation of granitic pegmatites is present, the pegmatites richest in lithium minerals are farthest from the center of the associated body of granite. 5. In pegmatite bodies that contain spodumene from wall to wall except for discontinuous, narrow border and, or, wall zones, many or almost all of the spodumene crystals are oriented with their long axes perpendicular to the walls, and are too fine-grained to be hand-sorted on a commercial scale. 6. Cleavelandite is generally a principal component of the wall zones. 7. In a given internal structure unit, spodumene is one of the early minerals to form. 8. Replacement bodies containing spodumene have not been found. 9. Amblygonite and montebrasite have been found only in intermediate zones.

Spodumene is the most abundant lithium mineral and it occurs in intermediate zone deposits, in thinly lenticular pods, and in pegmatite bodies that are essentially spodumene-bearing from wall to wall.

The bulk of the present lithium reserves in Canada is contained in pegmatite bodies that are essentially spodumene-bearing from wall to wall. These bodies are typically dike-like or thinly lenticular in shape. The grade and grain size of the spodumene in deposits of this type are remarkably uniform. At present, two companies are considering the development of such deposits in the Preissac-Lacorne district, Quebec.

## INTRODUCTION

THE occurrence of lithium-rich, granitic pegmatites in Canada has been known for many years, but there has been only a small production of lithium minerals. In 1951, the Geological Survey of Canada began geological studies of pegmatitic mineral deposits in Canada, and many of the lithium-rich pegmatites have been examined in detail (1, 2, 3).[2]

The primary purpose of the studies was to obtain information concerning the occurrence and distribution of the pegmatites, the relationship of economic minerals to internal structure, and data on the grade and tonnage of deposits. Although eight of the lithium deposits have been diamond drilled,

[1] Published by permission of the Deputy Minister, Department of Mines and Technical Surveys, Ottawa. Presented before the Society of Economic Geologists, Toronto meeting, Nov. 1953.

[2] Numbers in parentheses refer to References at end of paper.

in general, the drilling was preliminary and very little data concerning tonnages is available.

The deposits have been studied using techniques and terminology developed by the United States Geological Survey during wartime studies of strategic mineral deposits in the major pegmatite districts of the United States (4). Certain pegmatites, that were selected because of their economic or scientific interest, have been mapped by plane table methods, and hundreds of associated pegmatites have been examined visually.

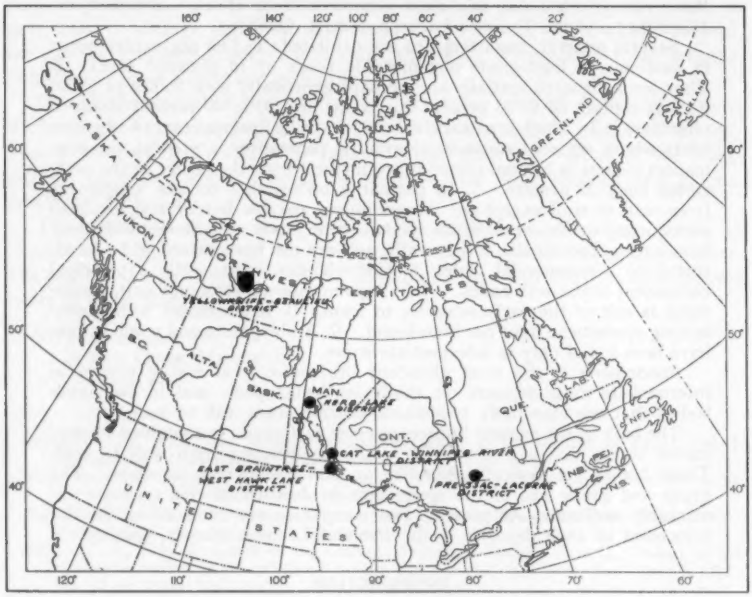


**Figure 1 - Location of Principal Lithium Pegmatite Districts in Canada.**

In addition to the geological studies, the Mines Branch, Ottawa, and private agencies have conducted ore dressing and extractive metallurgical tests on material from Canadian lithium deposits.

Because of the increasing demand for lithium products, considerable attention is being paid to Canadian lithium deposits by mining and chemical companies in Canada and the United States, and at least two companies are now considering development of their properties in Quebec.

Deposits of interest occur in the Yellowknife-Beaulieu district, Northwest Territories; in the Cat Lake-Winnipeg River, the Herb Lake, and East Braintree-West Hawk Lake districts, Manitoba; and in the Preissac-Lacorne district, Quebec (Fig. 1).

The writer thanks the many people who generously supplied information and extended courtesies during the studies.

He is especially indebted to Mr. E. L. Brown, Sherritt Gordon Mines Ltd.; Dr. D. R. Derry, Ventures Limited; Mr. Maurice Scott, Sullivan Consoliated Mines, Ltd.; and Mr. J. S. Richards and Dr. G. H. Charlewood, director and chief geologist, respectively, Manitoba Mines Branch, for detailed information concerning the Herb Lake deposit, the Lacorne Lithium Mines property, the Quebec Lithium Corporation property, and the Manitoba lithium deposits.

Capable field assistance was given by Mr. R. W. Hutchinson in 1951, Mr. J. R. Nixon in 1952, and by Messrs. H. Rasian and L. Berman in 1953.

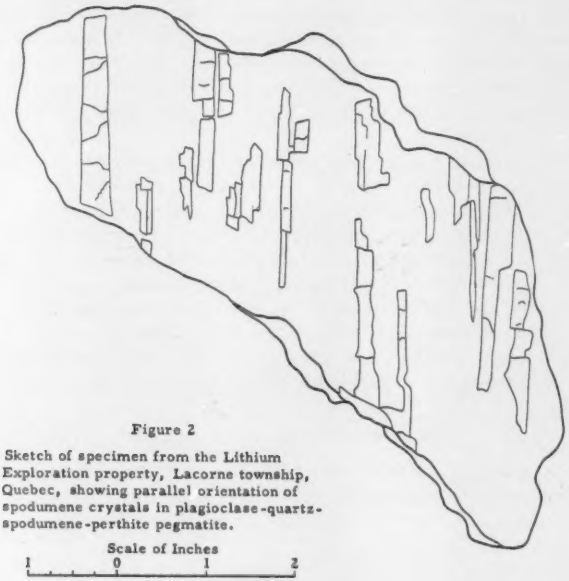


Figure 2

Sketch of specimen from the Lithium Exploration property, Lacorne township, Quebec, showing parallel orientation of spodumene crystals in plagioclase-quartz-spodumene-perthite pegmatite.

## MINERALOGY

The following lithium minerals have been found in Canadian pegmatites: amblygonite, lepidolite, various lithia micas, lithiophylite, montebrasite, petalite, spodumene, triphylite, and zinnwaldite.

Spodumene is by far the most abundant of the lithium minerals. It ranges from white to buff to green in color, and from less than ½ inch to more than 12 feet in length. Extremely elongate crystals have been observed, one of which was 18 inches in length and ½ inch in width. In general, the spodumene crystals are euhedral with ragged ends. Spodumene crystals veined by the groundmass minerals have been observed at several localities, suggesting that spodumene was one of the early minerals to form. In several pegmatites,

many or almost all of the spodumene crystals are oriented with their long axes perpendicular to the walls of the pegmatite body (Fig. 2). Some of the pegmatites of the Yellowknife-Beaulieu district carry spodumene that is intergrown with quartz, feldspar, or both at the outer margin of spodumene-bearing zones. Quartz-spodumene aggregates that look like coarse-grained crystals at a distance are present in some of the zoned pegmatites of the Cat Lake-Winnipeg River district. The spodumene of these aggregates occurs as fine- to medium-grained [3] needles that have a parallel orientation, and as sugary grains. In general, the spodumene is fresh, but it may be partly or completely altered to a dark green to black, woody substance that retains the outline and cleavage of spodumene, or to lithia mica. The dark green alteration has been noted at the outer margins of spodumene-bearing zones in certain pegmatites, but in some deposits there is no apparent control and only scattered spodumene crystals are affected. At some localities the spodumene crystals are partly or completely coated with a brown, limonite-like substance. Spodumene is commonly associated with quartz, plagioclase (in some cases the variety cleavelandite), and perthite.

Amblygonite and montebrasite are found in the intermediate zones of pegmatites, and are generally associated with quartz, cleavelandite, perthite, and spodumene. The crystals are mostly over 4 inches in maximum dimension, anhedral, and white to gray in color. In the Yellowknife-Beaulieu district, the amblygonite is polysynthetically twinned, and weathers to a chalk-like substance on exposed surfaces. At Bernic Lake, Manitoba, many of the Montebrasite crystals are oval in shape and rimmed by a brick-red substance.

Lepidolite and other lithia micas occur in replacement bodies, fracture fillings, or as replacements of other lithium minerals. Petalite has been found at two localities, but it is not sufficiently abundant to be of economic importance.

### YELLOWKNIFE-BEAULIEU DISTRICT

*General Geology.*—The Yellowknife-Beaulieu district is underlain by Precambrian rocks consisting of lavas, pyroclastic rocks, graywacke, impure quartzite, and slate of the Yellowknife group, their altered equivalents, and granitic rocks (5, 6, 7, 8, 9).

Isoclinally folded rocks of the Yellowknife group were intruded by granodiorite, folded along near-vertical axes, and intruded by granite and associated pegmatites. The metamorphic grade of the Yellowknife group increases toward the contacts with the granodiorite and granite, so that masses of granodiorite and granite are surrounded by aureoles of medium- to high-grade metamorphic rocks. Change in metamorphic grade is indicated by: the appearance of biotite at the expense of chlorite and sericite; the disappearance of car-

[3] The following classification of texture is used:

| Term | Crystal dimension (Inches) |
|---|---|
| Very fine-grained | − ¼ |
| Fine grained | ¼ to 1 |
| Medium grained | 1 to 4 |
| Coarse grained | 4 to 12 |
| Very coarse grained | + 12 |

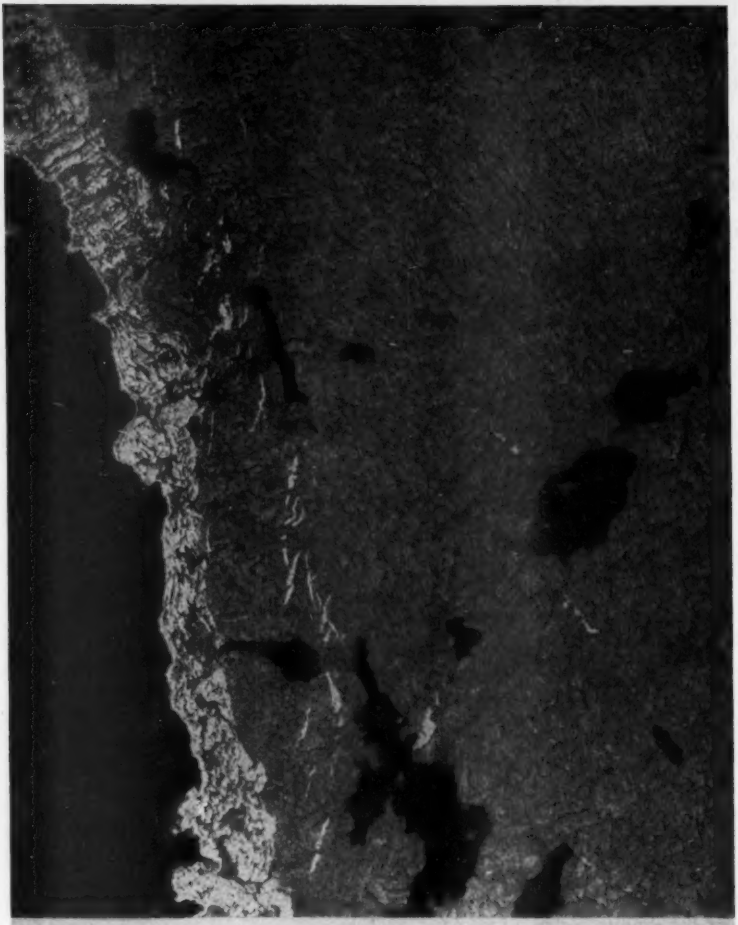

Figure 3

Air photograph showing spatial relationship of granitic pegmatites to a body of granite, Yellowknife-Beaulieu district, Northwest Territories. The pegmatites occur in medium- to high-grade metamorphic rocks.

bonate; increase in grain size; recrystallization of detrital quartz and albite grains; and "knots" having an average diameter of $\frac{1}{4}$ to $\frac{1}{2}$ inch. Many of the knots are nebulous aggregates, but, where well crystallized, are found to be composed of cordierite, and, less commonly, andalusite and staurolite.

The granite is fine to medium grained, gray to red weathering, and consists of 25 to 35 percent quartz, 30 to 40 percent microcline, 20 to 30 percent oligoclase, and 5 to 10 percent biotite and muscovite. It generally contains only a very few inclusions, and wall-rock contacts are knife-edge sharp.

*Pegmatites.*—Granitic pegmatites, some of which contain beryl, columbium-tantalum minerals, amblygonite, and spodumene occur in the medium- to high-

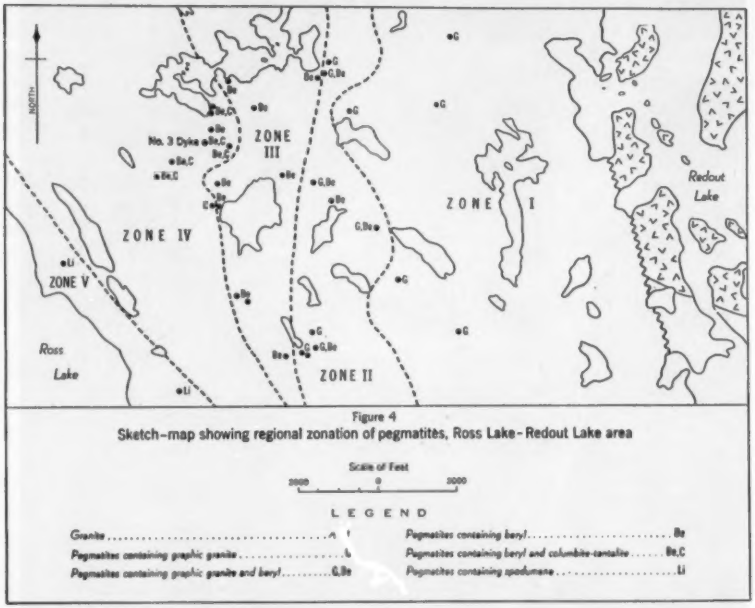


Figure 4
Sketch-map showing regional zonation of pegmatites, Ross Lake-Redout Lake area

grade metamorphic rocks that surround the granite bodies or in granodiorite near the granite bodies (Fig. 3).

The size and shape of a pegmatite body in the region is controlled primarily by its proximity to a mass of granite: those close to the granite tend to be large and irregular in shape, whereas those farther from the granite are more regular in shape and smaller. Most of the pegmatites containing commercial minerals are less than 30 feet wide and 500 feet long, and are generally lenticular or tabular masses.

A regional zonation of granitic pegmatites outward from the Redout Lake granite body in the Redout Lake-Ross Lake area has been observed (1, p. 10 and 9, p. 10). Five regional zones have been outlined (Fig. 4). The first

zone, the zone closest to the granite, contains large, irregularly shaped pegmatites that have poorly developed internal structure and contain graphic granite. In the second zone, some of the pegmatites contain beryl in addition to graphic granite, tend to be lenticular, and have a somewhat better developed internal structure. The third zone contains many pegmatites having beryl as a component but no graphic granite. These pegmaties are lenticular in shape, are smaller than those of the first two zones, and have well-developed internal structure. The pegmatites of the fourth zone are structurally similar to those of the third, but many contain columbium-tantalum minerals as well as beryl. The fifth zone, the zone farthest from the granite, features pegmatites that are spodumene-bearing.

*Deposits.*—The outstanding characteristics of pegmatites containing amblygonite and spodumene in the Yellowknife-Beaulieu district are as follows:

1. The pegmatites are related spatially and perhaps genetically to bodies of granite (Fig. 3).
2. They are exterior pegmatites [4] and occur in medium- to high-grade metamorphic rocks and granodiorite.
3. They are zoned and generally contain a border zone, wall zone, one or more intermediate zones, and a core.
4. Amblygonite and spodumene occur in intermediate zones.
5. Spodumene is by far the more abundant lithium mineral, and is green in color, and generally over 4 inches in length.
6. Cleavelandite is a major constituent of the wall zones.
7. Columbite-tantalite and beryl are common accessory minerals in the wall zones.
8. In some deposits, spodumene is altered to a dark green to black substance or is intergrown with quartz and, or, feldspar near the outer margins of the spodumene-bearing zones.

Very little information has been obtained concerning the grade and tonnages of these deposits because of the complete lack of subsurface data, and because the lithium minerals are not evenly distributed in the zones in which they occur. The richest spodumene-bearing zones probably contain 20 to 30 percent spodumene.

It is unlikely that all of the lithium-rich pegmatites in this district have been found, and further prospecting in the medium- to high-grade metamorphic rocks should produce new discoveries.

### CAT LAKE-WINNIPEG RIVER DISTRICT

The Cat Lake-Winnipeg River district is well known because of the occurrence of pegmatites containing lithium, beryllium, columbium-tantalum, and tin minerals; copper-nickel deposits; and the Bird River peridotite-gabbro sill with its associated chromium deposits. Uraninite from pegmatite on the Huron claim is of particular scientific interest because of its extreme antiquity.

[4] Exterior pegmatites are pegmatites that occur outside the related granitic body; marginal pegmatites occur in the marginal portion of the granitic body or in the immediately adjacent rocks; and interior pegmatites are found in the interior part of the related granitic body (13, 14).

Small amounts of lepidolite, montebrasite, and spodumene have been shipped from the region, and, in the past few years, considerable interest has been shown in the spodumene-bearing pegmatites at Cat Lake.

*General Geology.*—The consolidated rocks of the Cat Lake-Winnipeg River district are Precambrian in age, and consist principally of the very old Rice Lake group of folded meta-sedimentary and meta-volcanic rocks, and a younger group of granitic rocks: other rocks include acidic to basic dyke rocks, basic to ultrabasic intrusive rocks, and pegmatites (10, 11).

The granitic rocks have been divided by Stockwell (11, 12) into three groups that are probably differentiates of a single magma; an oligoclase granite group, a microcline granite group, and an albite granite group. He considers the oligoclase granite group to be a marginal phase of the microcline granite group, and the albite granite group to be a late differentiate. The average composition of the microcline granite group is as follows: potash feldspar, 37.1 percent; plagioclase, 28.1 percent; quartz, 30.0 percent; biotite, 3.3 percent; and other minerals, 1.5 percent.

*Pegmatites.*—The numerous granitic pegmatites of the district have been divided by Stockwell (12) into four types: microcline pegmatites; microcline-albite pegmatites; albite pegmatites; and albite-lithium pegmatites.

Microcline pegmatites are composed principally of microcline and quartz, and, in some cases, albite or oligoclase. Biotite, muscovite, and magnetite are common accessory minerals, whereas cleavelandite, beryl, tourmaline, garnet, titanite, apatite, molybdenite, pyrite, and arsenopyrite are less common accessory minerals. These pegmatites occur as interior and marginal pegmatites with respect to bodies of both microcline and albite granites, and are found in oligoclase granite, and metamorphic rocks, as well as in the microcline and albite granites. The interior pegmatites commonly grade into the inclosing rocks. Marginal pegmatites occurring in oligoclase granite generally increase in number as the microcline granite contact is approached.

Microcline-albite pegmatites occur as interior and marginal pegmatites with respect to albite granite bodies, and are found in albite granite, oligoclase granite, and metamorphic rocks.

Albite pegmatites are composed chiefly of albite, commonly the variety cleavelandite, and quartz. Small amounts of microcline are commonly present. Common accessory minerals include: muscovite, tourmaline, and garnet, whereas biotite, apatite, beryl, green tourmaline, purpurite, zoisite, uraninite, and monazite are less commonly found. The albite pegmatites are interior and marginal with respect to bodies of albite granite, and occur in albite granite, oligoclase granite, and metamorphic rocks.

Albite-lithium pegmatites are marginal and exterior with respect to albite-granite bodies, and exterior with respect to microcline granite bodies. They occur in albite granite, oligoclase granite, and meta-volcanic rocks. Albite, generally the variety cleavelandite, quartz, and muscovite are the chief minerals. Lithium minerals found in these pegmatites include one or more of the following: lepidolite, zinnwaldite, and various other lithia micas; lithiophylite; montebrasite; spodumene; and triphylite. Black, green, and pink

tourmaline, garnet, apatite, beryl, topaz, fluorite, purpurite, columbite-tantalite, monazite, podolite, and calcite are accessory minerals.

*Deposits.*—Although the granitic pegmatites of the Cat Lake-Winnipeg River district occur in a variety of rocks, those containing lithium minerals are found only in meta-volcanic rocks, or in granitic rocks close to the contact with meta-volcanic rocks.

All of the lithium-rich pegmatites that have been examined have internal structure. Montebrasite and spodumene occur in zones or lenticular pods, whereas lepidolite and other lithia micas occur in replacement bodies, fracture fillings, and as replacements of other minerals.

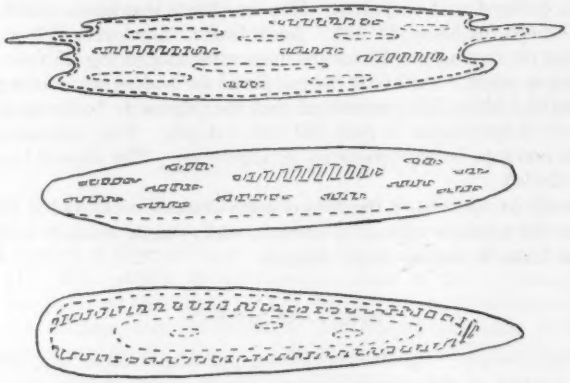


**Figure 5**

**Idealized plans showing the internal structure of spodumene-bearing pegmatites, Cat Lake - Winnipeg River district, Manitoba.**

Spodumene is by far the most abundant lithium mineral. It is white in color in some pegmatites, and pale green in others, and does not occur in crystals of sufficient size to be hand-sorted on a commercial scale.

Spodumene-bearing pegmatite bodies range in size up to 1,260 feet in length and 65 feet in width, and are generally lenticular or tear-drop in shape in plan. In some pegmatite bodies, spodumene occurs in continuous or discontinuous intermediate zones, whereas in others it occurs in thinly lenticular pods. Quartz-spodumene aggregates that look like coarse- to very coarse-

grained crystals at a distance are present in some of the intermediate zone deposits. The spodumene of these aggregates occurs as fine- to medium-grained needles that have a parallel orientation, and as sugary grains. The aggregates generally lay in a groundmass of quartz and cleavelandiate, with or without lithia mica. Figure 5 illustrates the internal structure of spodumene-bearing pegmatites in the district.

In the largest spodumene-bearing pegmatite body of the region, the Irgon dike, most of the spodumene occurs in lenses of quartz-spodumene-perthite pegmatite. The spodumene generally occurs as milky-white or pale green plates ranging up to 4 inches in length. Very little surface work has been done, and outcrops are now so badly obscured by vegetation that the lenses cannot be outlined with certainty. One lens has a maximum width of 4 feet, and was traced for about 25 feet. According to Stockwell (11, p. 124), an area of quartz-spodumene-microcline pegmatite measuring 45 feet in length and 12 feet in width occurs near the middle of the widest part of the body.

Stockwell (11, p. 125) estimated that the pegmatite body contains about 25,000 tons of spodumene in each 100 feet of depth. This estimate was made before the outcrops became obscured by vegetation. The deposit has not been diamond-drilled.

Thorough prospecting in the belts of meta-volcanic rocks and in the granitic rocks near the contacts with meta-volcanic rocks should uncover new deposits in the Cat Lake-Winnipeg River district.

### HERB LAKE DISTRICT

*General Geology.*—Spodumene-bearing pegmatites occur in quartz diorite near the contact of the quartz diorite with microcline-biotite granite. According to Stockwell (15, p. 11), the quartz diorite is a border phase of the granite. He believes that the pegmatites are derived from the granite.

Deposit—Several spodumene-bearing pegmatites have been found, and one of these, which occurs on property held by Sherritt Gordon Mines Ltd., has been traced for a distance of 900 feet by diamond drilling. Nineteen diamond drill holes, placed at intervals of about 50 feet, intersected the pegmatite at an average depth of about 50 feet, and a twentieth hole intersected it at about 150 feet. The pegmatite intersected by the nineteen shallow holes contains an average of 13.57 percent spodumene over an average width of 18.5 feet, whereas the deeper hole intersected 14 feet of pegmatite containing 23.1 percent spodumene. Apparently, the pegmatite body cut by the diamond drill holes can be considered as spodumene-bearing from wall to wall for practical purposes.

Most of the outcrops consist of perthite-cleavelandite-quartz-spodumene-muscovite pegmatite. In places, black tourmaline, red garnet, and blue-green triphylite are present in minor amount. A few small crystals of golden beryl were found in broken rock. The spodumene crystals are apple-green and range up to about 1.5 feet in length, and crushing to plus $\frac{1}{4}$ inch minus $\frac{1}{2}$ inch liberates most of the spodumene. In places, many of the spodumene crystals are oriented with their long axes perpendicular to the wall-rock contact.

### EAST BRAINTREE-WEST HAWK LAKE DISTRICT

Several spodumene-bearing pegmatites have been found in an east-west band of meta-volcanic rocks of Precambrian age that has traced from the settlement of East Braintree to West Hawk Lake, a distance of about 20 miles (11, p. 126, 16). The band averages about 1.5 to 2 miles in width, and is bounded on the north and south by granodiorite containing phenocrysts of microcline and microcline perthite. One of the spodumene pegmatites has been diamond drilled (16, p. 20), but no further work has been undertaken. Because the district is well supplied with transportation facilities, further prospecting is warranted.

It is of interest to note that Stockwell (12, p. 24) has observed a regional zonation of pegmatites near West Hawk Lake. Microcline pegmatites were found over a distance of $\frac{1}{2}$ mile from a body of microcline granite, microcline-albite pegmatites between $\frac{1}{2}$ and $\frac{3}{4}$ of a mile, and three lithium pegmatites at $1\frac{1}{2}$, $2\frac{1}{4}$ and $2\frac{1}{2}$ miles. Two albite pegmatites were found at 600 feet and $\frac{3}{4}$ mile from the granite.

### PREISSAC-LACORNE DISTRICT

*General Geology.*—The consolidated rocks of the district are Precambrian in age, and consist of meta-volcanic rocks, meta-sedimentary rocks, and large and small masses of plutonic rocks ranging from acidic to ultra basic in composition (17, 18). Acidic to intermediate rocks of the Preissac-Lacorne batholith are the most abundant rocks of the region, and have intruded closely folded, meta-volcanic, meta-sedimentary, and altered ultrabasic rocks. Pegmatites, aplites, and quartz veins occur in the rocks of the batholith, and in the metamorphic rocks near the batholithic contact.

The Preissac-Lacorne batholith extends for more than 30 miles east-west, and averages 12 to 14 miles in width. Gussow (19) divided the rocks of the batholith into two main types: hornblende granodiorite, and garnetiferous muscovite leucogranite. Norman (20, p. 3) described the rocks as a diorite-syenite-granodiorite-granite group. Six main rock types were recognized by Tremblay (18, p. 30): hornblende monzonite, biotite-hornblende granodiorite, amphibolite, biotite granodiorite, muscovite granite, and pegmatite material.

The principal rock type of the batholith is muscovite granite, which has the following average mineral composition according to Tremblay: albite, 40 per cent; microcline, 24 percent; quartz, 31 percent; muscovite and accessory minerals, 5 percent.

K. R. Dawson of the Geological Survey is making a detailed study of the Preissac-Lacorne batholith.

*Pegmatites.*—Granitic pegmatites, some of which contain spodumene, feldspathic quartz veins, and quartz veins are associated spatially, and perhaps genetically, with the Preissac-Lacorne batholith. The pegmatites and veins occur both in the rocks of the batholith and in the adjacent metamorphic rocks, and are most abundant near the contact. Most of the known pegmatites containing beryl, columbite-tantalite, or spodumene occur in two distinct belts (Fig. 6). One belt extends along the northern contact of the batholith,

whereas the other extends from the northern contact to just south of Lake Lusignan, and lies just east of Lake Okikeska.

A regional zonation of pegmatites and veins occurs about the batholith (2, 18, 20). Three regional zones are present: a beryl zone with some of the pegmatites containing beryl but no lithium minerals; a lithium mineral zone with some of the pegmatites containing lithium minerals but very little beryl; and a molybdenite zone containing veins that carry molybdenite (Fig. 6). In general, it seems that beryl occurs in greatest concentration in pegmatites within the batholith, and spodumene in pegmatites within the batholith near

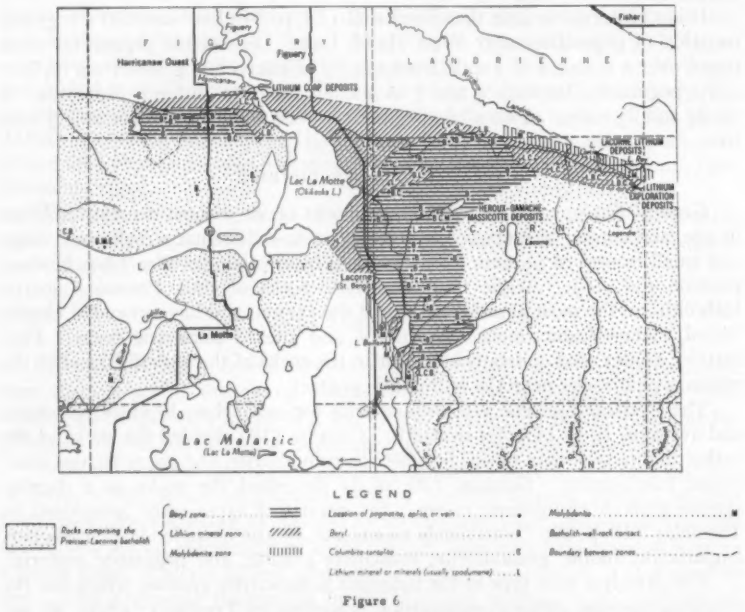


Figure 6

**Map of the region of the Preissac-Lacorne batholith, Abitibi county, Quebec, showing occurrences of beryllium, columbium-tantalum, and molybdenum minerals.**

the contact and in metamorphic rocks adjacent to the contact. There is also a variation in the potash feldspar content of the pegmatites. Those containing the greatest concentrations of beryl have a higher potash feldspar content than the pegmatites containing the greatest concentrations of spodumene.

A detailed study made by Tremblay (18) of the strikes and dips of the pegmatite bodies in Lacorne township suggests that these bodies are related to structural features associated with the Preissac-Lacorne batholiths. Pegmatites near the contacts strike either parallel with, or at right angles to, the contacts, suggesting that the intrusion of the pegmatites was controlled by

longitudinal and cross joints. The orientation of pegmatites within the batholith also suggests a control by joint systems.

*Deposits.*—Spodumene is the only lithium mineral occurring in sufficient abundance to be of economic interest in the Preissac-Lacorne district. It is white to buff in color in some deposits and green in others, and, in general, is too fine grained to be hand-sorted on a commercial scale.

All of the spodumene-bearing pegmatites examined feature internal structure, with the possible exception of pegmatites on the Lacorne Lithium Mines property south of Lake Lortie which apparently carry spodumene from contact to contact (21). Several of the spodumene pegmatites contain a border zone, wall zone, and apparent core. The border and wall zones are very narrow, and are not continuous around the pegmatite bodies. Innermost zones or apparent cores consist of plagioclase, quartz, spodumene (ranging up to 8 inches in length, but commonly less than 4 inches), and perthite, and comprise the bulk of these pegmatite bodies.

Diamond drilling on the Lacorne Lithium Mines property has outlined about 300,000 tons of spodumene-bearing pegmatite contained in one large and two smaller pegmatite bodies that are apparently spodumene-bearing from wall to wall (21). The average spodumene content of this rock is probably about 20 per cent.

An extensive diamond drilling program has been undertaken by the Quebec Lithium Corporation (formerly Lithium Exploration Company Limited) on the company's property. Eighty diamond-drill holes, totalling over 30,000 feet, have been put down, and several spodumene-bearing pegmatite bodies have been intersected. The pegmatites contain an average of 53 percent feldspar, 30 percent quartz, and 17 percent spodumene. One large body was cut by forty-one diamond-drill holes, and it has been calculated that the body, as outlined, contains over 2,000,000 tons of rock with an average lithium oxide content of 1.20 percent.

Careful prospecting in the marginal areas of the batholith, particularly in the two belts previously mentioned, should uncover new deposits.

## GENERAL CHARACTERISTICS OF LITHIUM PEGMATITES

The following general characteristics are exhibited by pegmatites in Canada that contain appreciable amounts of lithium minerals:

1. The pegmatites occur in medium- to high-grade metamorphic rocks or in plutonic rocks.
2. They are associated spatially and perhaps genetically with bodies of granite that contain 20 to 40 percent microcline and 20 to 40 percent albite or oligoclase.
3. They are marginal and exterior pegmatites.
4. In districts where regional zonation of granitic pegmatites is present, the pegmatites richest in lithium minerals are farthest from the center of the associated body of granite.
5. In pegmatite bodies that contain spodumene from wall to wall except for discontinuous, narrow border and, or, wall zones, many or almost all of

the spodumene crystals are oriented perpendicular to the walls, and are too fine-grained to be hand-sorted on a commercial scale (Fig. 2).

6. Cleavelandite is generally a principal component of the wall zones.

7. In a given internal structural unit, spodumene is one of the early minerals to form.

8. Replacement bodies containing spodumene have not been found.

9. Amblygonite and montebrasite have been found only in intermediate zones.

## ECONOMIC OUTLOOK

The occurrence of pegmatitic lithium deposits in Canada has been known for many years, but there has been very little production of lithium minerals. Preliminary geological, metallurgical, and economic studies indicate the possibility of a lithium industry in Canada.

It is not likely that the known deposits of the intermediate zone and replacement body types will be developed in the near future. The richest deposits of the intermediate zone type occur in the Yellowknife-Beaulieu district where the costs of shipping lithium mineral concentrates are formidable. Should sufficient tonnages of lithium minerals be proven to warrant the construction of a local plant to produce lithium compounds, transportation costs would be overcome in part. Small tonnages of lepidolite, montebrasite, and spodumene have been recovered from time to time from intermediate zone and replacement body deposits in the Cat Lake-Winnipeg River district, but, in general, the deposits are relatively low in tonnage and it is not feasible to provide the region with adequate transportation facilities at present.

The Irgon pegmatite in the Cat Lake area contains lenticular, spodumene-bearing pods, and is possibly a large tonnage source of fine- to medium-grained spodumene. The deposit has not been diamond drilled and very little surface work has been done. It would not be feasible to mine the pods selectively so that this occurrence is obviously very hard to evaluate.

The bulk of the present lithium reserves in Canada is contained in pegmatite bodies that are essentially spodumene-bearing from wall to wall. The pegmatite bodies are typically dike-like or thinly lenticular in shape. Spodumene occurring in these deposits is too fine-grained to be hand-sorted on a commercial scale, but concentration tests by the Bureau of Mines, Ottawa, and other agencies have produced encouraging results. The grade and grain size of the spodumene are remarkably uniform.

Several deposits of this type occur in the Preissac-Lacorne district, Quebec, and are particularly well situated with respect to existing transportation facilities. Although these deposits are not close to large manufacturing centers, the possible tonnages are large and the transportation difficulties could be largely overcome by the erection of a local plant to produce lithium compounds.

There is a possibility that feldspar could be produced as a by-product or co-product of lithium mining operations in the Preissac-Lacorne district. A chemical analysis of feldspar concentrate obtained by concentration tests on spodumene-bearing pegmatite from the Lacorne Lithium Mines property, Lacorne township, gave the following results: sodium oxide, 9.98 percent; potas-

sium oxide, 4.06 percent; aluminum oxide, 19.64 percent; silicon dioxide, 67.80 percent; lithium oxide, 0.46 percent; and ferric and titanium oxides, 0.034 percent (21).

The Preissac-Lacorne deposits have not been developed because of uncertainties concerning market conditions. There is apparently little or no demand for lithium minerals or compounds in Canada, but numerous enquiries from companies in the United States and elsewhere indicate that there is a strong demand on the world market for lithium mineral concentrates, and perhaps lithium compounds, metallic lithium, and lithium products. At present, two companies are considering the development of spodumene deposits in the Preissac-Lacorne district.

GEOLOGICAL SURVEY OF CANADA,
OTTAWA, ONTARIO,
*Dec. 24, 1953*

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# ALTERATION ASSOCIATED WITH ORE AT GASPE COPPER MINES

A. M. BELL AND F. J. SCOTT

ABSTRACT

The geology of the copper deposits now being developed by Gaspe Copper Mines in the Gaspe Peninsula is summarized in this paper with attention restricted to metamorphism in the host rocks associated with ore replacement. The ore occurs in faulted and gently folded Palaeozoic sediments and seems derived from a buried stock of granite. The best orebody is a replacement in a limestone bed and lies up-dip from the intrusive. The deeper end of this limestone ore approaches within half a mile of the granite and the upper end is one and one-quarter miles away, with the ore confined to an area of lime-silicate alteration. More siliceous sediments above and below the limestone bed have been bleached and silicified over a two-square mile area. All known ore deposits in these rocks are within the altered zone. The chemical changes accompanying hydrothermal alteration in these ore horizons, which were originally different in composition, are compared. In each case a marked net gain in silica and a corresponding loss in lime is indicated. Quantitatively some 500 tons of silica seem to have been deposited in the host rocks for every ton of copper. In rocks low in calcite, the silicification is widespread and is not a specific guide to the location of ore within the zone of alteration. In limestone rocks alteration is less widespread and is a useful guide in locating ore.

Copper ore deposits occur in the metamorphosed equivalents of one or more formation of the Gaspe Limestone Series of Lower to Middle Devonian Age. The general picture was given in a paper [1] presented to the Canadian Institute of Mining and Metallurgy in 1950, and need not be reviewed here.

The present discussion will deal only with the ore occurrences on Needle Mountain. The structural picture is that of ore deposits occurring in three sedimentary formations on the crest and north flank of the Needle Mountain anticline. An intrusive center lies in the syncline, one mile north of the anticlinal crest, and solutions that produced both the metamorphism of the ore-bearing rocks, and the ore deposits themselves, can be assumed to have funnelled out from this center.

The rocks over a surface area of two square miles have been subject to hydrothermal alteration, which has had a bleaching effect that markedly distinguishes them from the dark rocks of the surrounding area. All important copper deposits have been found within this altered zone.

The Needle Mountain orebodies under consideration occur in three formations. These are:

[1] Geology of Ore Occurrences at the Property of Gaspe Copper Mines, by A. M. Bell, Canadian Institute of Mining and Metallurgy, Transactions, Volume LIV, 1951.

"A" Ore Zone—occurring in an upper horizon, 500 feet thick, that was originally composed of dark calcareous siltstone and has altered to a white, fine grained quartzite.

"B" Ore Zone—occurring in a middle horizon, 120 feet thick, composed originally of siliceous limestone, which has been altered to a wollastonite-diopside rock.

"C" Ore Zone—occurring in a lower limestone formation averaging 110 feet thick, whose altered equivalent is garnet-diopside skarn.

These three formations provide country rock representing a wide variation in lime and silica content. This affords a study in the different effects produced on each type by similar hydrothermal solutions. The ore depositing solutions are no doubt a phase of these.

TABLE I
PHYSICAL EFFECTS OF ALTERATION

| | "A" ZONE | "B" ZONE | "C" ZONE |
|---|---|---|---|
| Unaltered Rock | Dark Siltstone | Dark Siliceous Limestone | Dark Limestone |
| Altered Rock | White Silicated Quartzite | Wollastonite Rock - White | Garnet Diopside Skarn |
| Ore Type | Chalcopyrite - Pyrrhotite | Chalcopyrite - Pyrrhotite | Chalcopyrite - Pyrrhotite |
| Extent Alteration | 1.0 Square Mile plus | 1.0 Square Mile plus | 0.25 Square Mile plus |
| Ore Localization | Structural Control - Shattering (?) | Structural - by Faults - Part Earlier | Close to Margins and Tongues of Skarn |
| Value as Ore Indicator | General Area Only | General Only | Controls Position of Ore (Shrinkage makes ore channels) |
| Alteration Effects | (a) Bleaching with loss any carbon | Bleaching and carbon loss | Alteration confined to skarn portions |
| | (b) Lime concretions - lime silicates | Formation of Wollastonite - minor Diopside | |
| | (c) Increase in quartz grain size | | |
| | (d) Disappearance of Calcite - development of Sanadine | Disappearance of Calcite | |
| | (e) Volume change ? - beds preserved specific gravity same | Beds preserved - volume change doubtful specific gravity same. | 10% increase in S.G. 10% volume shrinkage. |

## PHYSICAL EFFECTS OF ALTERATION

The accompanying tabulation, Table I, attempts to indicate the physical changes produced in rocks of the three zones.

In the case of "C" zones it might be pointed out that the limestone formation differs markedly from the more siliceous formation above and below, in that the bed remains dark and unaltered except where skarn has developed. There is a rapid transition from skarn to dark limestone. This transition zone is marked by bleaching and recrystallization of calcite. Ore is generally in the skarn portions.

## CHEMICAL CHANGES IN ALTERATION

Graphs showing the composition changes in certain elements for unaltered rock, for altered rock and for ore bearing rock in each of the three ore zones

are shown in Figure 1. The analyses were made on composite samples carefully selected from a large number of drill holes, and in some cases from underground workings. In each case a composite sample of the same stratigraphic horizons of altered and unaltered rock was prepared. The greatest changes in each case are in lime and silica content.

The graphs for rocks of varying lime and silica content all show an apparent gain in silica and a very pronounced true loss in lime content. In the case of "C" Zone one can determine the change in specific gravity from

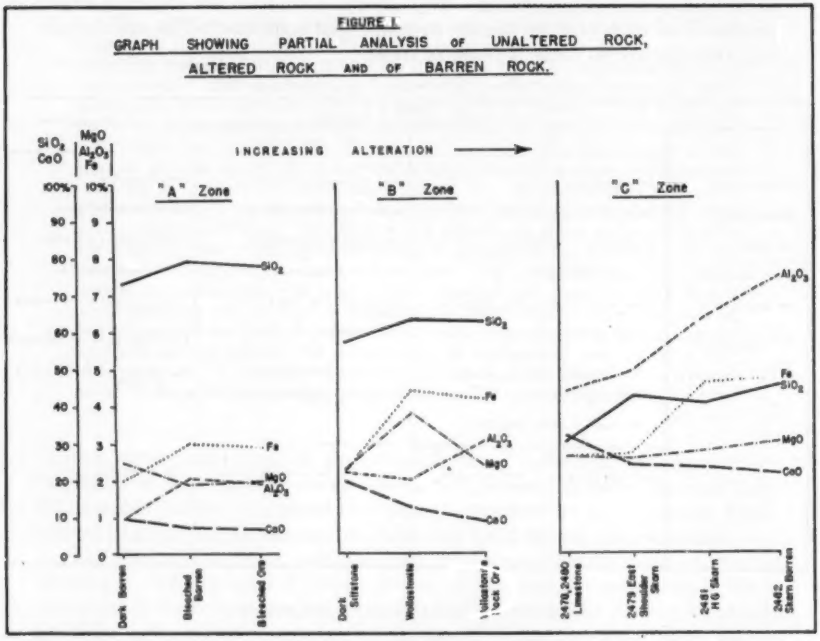


FIG. 1

altered to unaltered rock, and it has been found the change in volume in the alteration is a maximum of 10 percent of the original rock. In correcting for the increase in apparent silica assay by change in volume, one can account only for three parts per 100 of increase in silica, leaving 10 parts per hundred (30% increase) that seem to be a definite addition of silica.

In the case of the "A" Zone and the "B" Zone no change in specific gravity between altered and unaltered rock is indicated by measurements, and the preservation of bedding structures suggests the volume remained virtually constant during the alteration. If the volume has remained the same, an

increase in silica of six parts per 100 parts of rock in each zone has resulted. The silicates formed in these zones have lower specific gravities than in the "C" Zone, so no direct comparison as to a possible volume change proportionate to lime content in "C" Zone is possible. Even taking a possible maximum change in volume proportional to lime content into consideration, one cannot account for more than half the apparent gain in silica. It seems reasonable to believe that in the more siliceous rocks of the "A" and "B" Zones, a true gain in silica of some five parts per hundred parts of original rock has resulted, and that there was little volume shrinkage accompanying the alteration. The loss of lime amounting to 3 to 20 percent of the rock, or 25 to 50 percent of the original lime content is definite. Unlike lime, there is no loss of magnesia indicated in the general rock alteration. There is some evidence of loss of magnesia in the final stage of ore deposition. Other elements are too low to indicate any reliable trend. The exception to this would be aluminum, which clearly shows a net gain during alteration of the lime rock.

## CONCLUSIONS

In this area at least it can be concluded that alteration by silicification and loss of lime is a most useful general guide to the presence of copper deposits.

Quantitatively one can obtain an approximation of the gain in silica and loss in lime, commensurate with the tonnage of copper deposited. On the basis of chemical and physical studies there is every indication that silica has been added to all rocks in an area of some two square miles and having a vertical extent of at least 3,000 feet. We conclude that probably on the average the added silica amounts to five or six parts per 100 parts of original rock. The addition is twice this in limestone. Lime has definitely been lost in every case in amounts equal to 25 to 50 percent of the original lime content. In the overall alteration rock, this loss of lime could amount to some five parts per 100 parts of rock, or virtually the same as the implied gain in silica.

In the zone of alteration, there could then have been added some 500,000,000 tons of silica, and an equivalent loss of lime and volatiles. This would mean that some 500 times as much silica as copper had been introduced into the host rock. Investigation of other occurrences is suggested to see if any quantitative correlation between the net losses and gains resulting in rock alteration of an area bears any relation to the size of the mineral deposits that may have formed there.

In rocks that are not high in lime, the alteration at Gaspe is widespread and is no guide to the specific location of orebodies. Rather, ore controlled by fracturing or faulting or some structural features is found. Alteration may, however, indirectly produce some of these ore controls. As an instance, where the beds are brittle from silicification, folding has produced shattered zones, and elsewhere the spongy wollastonite zones have a bearing on faulting.

In the case of rocks high in lime, the alteration is more closely associated with ore and is commonly a useful guide to its location. Sulphides are lean

in the heart of the large mass of skarn occupying the lime horizon in the north section near the intrusive, but ore is found in the tongues of skarn and at the margins of the heavy silicates. Scott suggests that ore favors that part of the skarn that contains some 25 percent of the original calcite. Another reason for this association between skarn and ore may be that a shrinkage in volume accompanying development of silicates has afforded ore channels. These shrinkage channels would remain open near the margins, at a time when progressive alteration has sealed them in the interior of the skarn mass. The highest grade ore is always found where there is a sharp change from skarn to limestone.

If the host rocks have a high lime content, the alteration will be confined to certain portions and there will be no widespread silicification of the limestone, as is found with more siliceous rocks. It is suggested that this is due to the fact that the silica-bearing solutions may have had to progressively replace their way through a lime bed owing to the readiness of reaction between free lime and silica. Any shrinkage as silicates were formed would afford a constantly advancing channel. Limestone, a short distance away from these skarns, may be quite unaltered. Accordingly, if alteration in an area of lime rocks lacks uniformity, it does not follow that less hot solutions were active there than in places where rocks are more siliceous and alteration seems more general.

In searching for ore in skarn areas, the best place to look is in the projections of skarn farthest out from the center, because in such places there should have been open channels caused by shrinkage during the late stage in the advance of the solutions favored by metal deposition.

NORANDA MINES, LTD.,
TORONTO, ONTARIO, AND GASPE, QUEBEC,
*Dec. 8, 1953*

# THE JERSEY LEAD-ZINC DEPOSIT,[1] SALMO, B. C.

Q. G. WHISHAW

ABSTRACT

The orebody lies in a dolomitized zone at the base of a limestone bed in a series of lower Cambrian sediments. The sediments are isoclinally folded and the ore is in the upper limb of the fold. The ore minerals are pale-colored iron-free sphalerite, and galena. Silver is virtually absent but cadmium is associated with the sphalerite. Pyrite and some pyrrhotite are present.

The major control of ore deposition has been open and overturned folding. In places the folding is accompanied by brecciation and minor pre-mineral faulting. The ore occurs in the troughs and on the limbs of the folds. The sediments have been intruded by granite, which has formed a tactite or skarn zone beneath the ore. This zone is in places overfolded and high-grade ore occurs around the nose and within the overfold.

The deposit is typical of a type of world-wide distribution normally far removed from any igneous masses. The adjacent granite is not necessarily the source of the ore solutions.

Trace element analyses show considerable zinc in the overlying argillite and this is considered to be a possible source of the mineralization that has been concentrated in a favorable zone in the limestone by meteoric water.

THE Jersey lead-zinc mine of Canadian Exploration Ltd. is in southeastern British Columbia. It lies on the east side of the Salmo River valley at an elevation of 4,000 feet. It is 28 miles south of the town of Nelson, B. C., 12 miles north of the International Boundary, and 125 miles north of Spokane, Washington. (Fig. 1.)

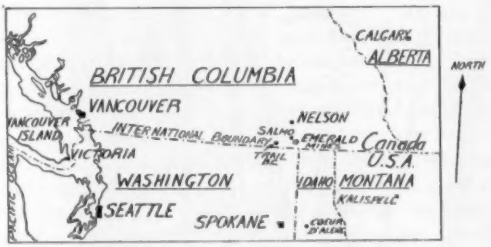


FIG. 1.

[1] Presented before the Society of Economic Geologists, Toronto Meeting, November, 1953.

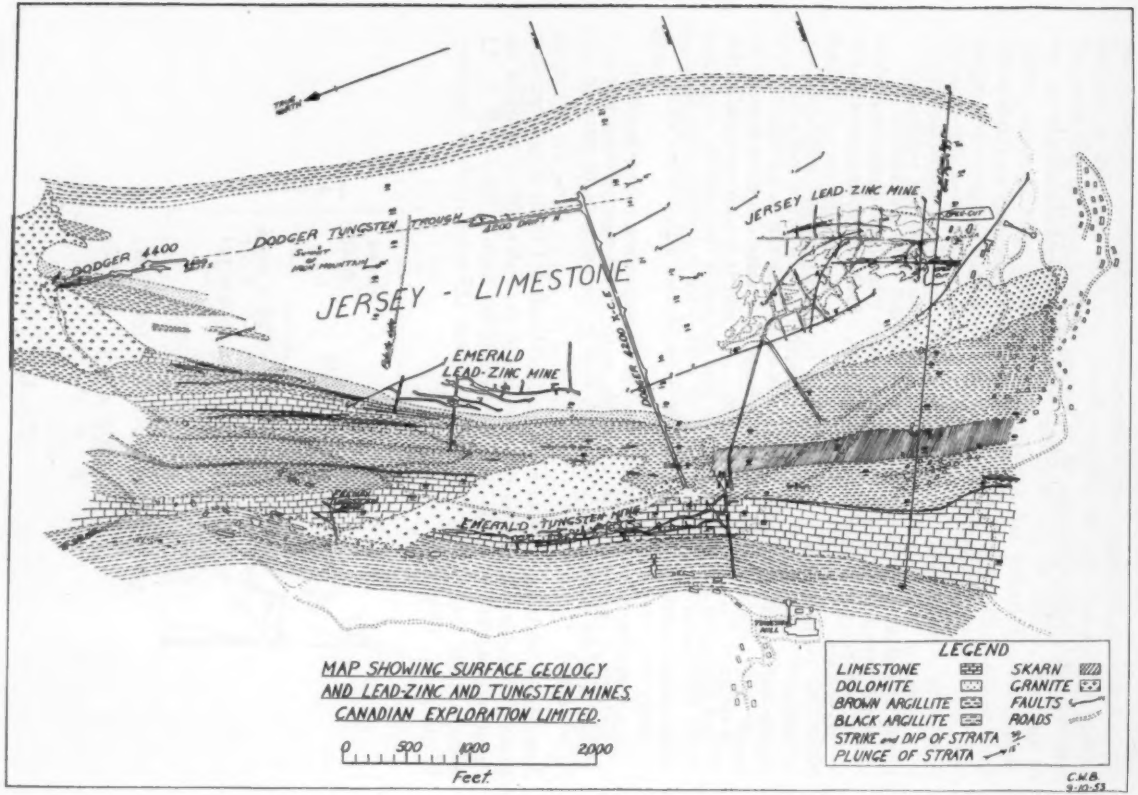
DODGER 4400
DODGER TUNGSTEN
TROUGH
4300 DRIFT N
JERSEY LEAD-ZINC MINE
OPEN-CUT
JERSEY - LIMESTONE
EMERALD
LEAD-ZINC MINE
4400 DRIFT S
EMERALD TUNGSTEN MINE
MAP SHOWING SURFACE GEOLOGY
AND LEAD-ZINC AND TUNGSTEN MINES
CANADIAN EXPLORATION LIMITED.
0 500 1000 2000
Feet
LEGEND
LIMESTONE
DOLOMITE
BROWN ARGILLITE
BLACK ARGILLITE
STRIKE and DIP OF STRATA
PLUNGE OF STRATA
SKARN
GRANITE
FAULTS
ROADS
C.W.B.
9-10-53

FIG. 2.

*Topography.*—The country is mountainous. The Salmo Valley is at an elevation of 2,000 feet and the highest peaks in the district reach 7,500 feet.

The valley is a typical "U" shaped glacial valley, as are the valleys of its tributaries, and the rounded contours of all but the highest peaks show that Pleistocene ice must have filled the valleys to an elevation of at least 6,000 feet. There is abundant glacial drift on the lower slopes of the mountains and in the valley bottoms.

*History.*—The mining history of the district dates back to about 1890, and intensive prospecting from then on resulted in the discovery of gold and lead-zinc deposits. The property of Canadian Exploration Ltd. was first staked in 1895, and from 1908 until 1936 intermittently, a small tonnage of high grade lead ore was mined from the Emerald mineral claim. In 1949, Canadian Exploration, having acquired the property chiefly for the tungsten ore bodies, with a fall in the price of tungsten, started mining lead-zinc ore from the same orebody previously mined, but on the Jersey claim several thousand feet to the south.

From then to the present time about one million tons of ore of an average grade of about 2% Pb and 6% Zn have been mined. Present reserves stand at about six million tons, of slightly lower grade.

## REGIONAL GEOLOGY

The district has been mapped by the Geological Survey of Canada on a scale of one mile to the inch, first by Walker in 1928 and 1929, and again by Little in 1949 and 1950. At present a party of the British Columbia Department of Mines is mapping selected areas on a scale of 1,000 feet to one inch. Large scale mapping of various mining properties has been undertaken by the owners.

The structure, once considered fairly simple, reveals greater complexity with increasing detail. Neither the stratigraphy nor the structure is as yet fully worked out. (Fig. 2.)

In general the area is underlain by a thick series of sediments that appear to be conformable from late Precambrian to the base of the Ordovician. Precambrian rocks outcrop on the east of the map sheet, and the Cambrian rocks are folded in a series of north-south trending anticlines and synclines that give rise to a repetition of the various formations across the center of the sheet.

The western part of the area is underlain by a predominantly volcanic series of Jurassic age, which lies unconformably over the Cambrian sediments. A large part of the south of the map area is underlain by black carbonaceous argillite, which has been correlated with the Ordovician Leadbetter Slate of the Metalline District south of the International boundary. If this correlation is correct, it must be in thrust fault contact with the Cambrian rocks.

Various granite masses intrude the sediments and are presumably outliers of the Nelson batholith to the north. This is believed to be Cretaceous in age. Two small stocks of monzonite are known in the district and numerous lamprophyre dikes cut all the other rock types.

About one and a half million tons of gold ore has been mined from quartz

veins in the quartzites of the lower Cambrian at the Sheep Creek camp. Various small operations have produced gold-copper ore from the Jurassic volcanics. Present mining activity centers on the lead-zinc replacement deposits in the limestone of the lower Cambrian, and on tungsten in tactite deposits at the contact of the granite and this same limestone.

In the vicinity of the mine the detailed stratigraphy is as follows.

| | |
|---|---|
| Leadbetter slate (Ordovician) | |
| Thrust fault | |
| Upper Laib argillite and argillaceous quartzite (Cambrian) | 2,000 feet |
| Black carbonaceous argillite | 300 feet |
| Limestone (Jersey) | 1,000 feet |
| Interbedded limestone and brown argillite | 100 feet |
| Limestone (base of Laib) | 20 feet |
| Quartzite and argillaceous quartzite (Reno) | 500 feet |

Recent work suggests that the Laib group and older rocks lie as an isoclinal fold overturned to the west, with an axial plane of 50 degrees and an axial line plunging about 12 degrees to the south. The apex of the fold has been eroded to the base of the Reno quartzite so that the two limbs of the limestone appear as two separate beds in outcrop. This structure is recognizable from north of the H. B. mine four miles to the north of the Jersey, to the Red Bird prospects ten miles to the south, near the International Boundary. The amplitude of the fold must be over 2,000 feet. Black carbonaceous argillite is in contact with the limestone to the east of the mine. The carbonaceous argillite stratigraphically above the limestone, which is Lower Cambrian Laib Group, is very similar in appearance to the Leadbetter Slate (Ordovician). Both are probably in contact with the limestone, so that some of the eastern contact is a thrust fault.

Three small granite outcrops occur in the vicinity of the mine and the area is known from drilling to be extensively underlain by granite. The rock is finer grained than the typical Nelson granite but is of the same type.

*Metamorphism.*—All the rocks show evidence of considerable regional metamorphism. The limestone is recrystallized to a black and white banded marble, and the argillaceous rocks contain much biotite. In places they approach biotite schist. The zone of interbedded limestone and argillite beneath the main limestone contains much impure limestone or limey argillite. Beneath the ore these beds have been folded and there is evidence of intense drag-folding and flowage. Much of this zone has been selectively altered to tactite (locally called skarn) with the formation of garnet and epidote. On the surface a number of skarn layers can be followed for several thousand feet. The pure limestone and the non-limey argillite as a rule remain unaltered. Some of the alteration is doubtless thermal only due to the proximity of the granite, but the distribution of the skarn in definite beds that are strongly altered many hundred feet from the granite contact indicates metasomatism caused by solutions from the granite. The selectivity of the alteration may be due to structure. The skarn beneath the ore is highly drag folded and crumpled. It seems possible that during the regional folding the limestone beds flowed and recrystallized, and the argillite became sheared, with the

development of mica, whereas the mixed rock became drag folded and crumpled, allowing the entry of solutions from the granite. The skarn is not a consistent marker horizon but has been useful in drilling in that it commonly marks the bottom of the ore horizon.

*Faulting.*—The thrust fault that is suspected to mark the eastern boundary of the limestone is a regional feature. Little is known about it except that the Ordovician rocks are in contact at one place or another with nearly every rock type in the district.

A number of minor faults occur in the mine. The south end of the ore zone is bounded on the west by a north-south striking east-dipping normal fault. Most of the upthrown limestone and ore has been eroded, but where present it indicates a displacement of 150 feet downward to the east.

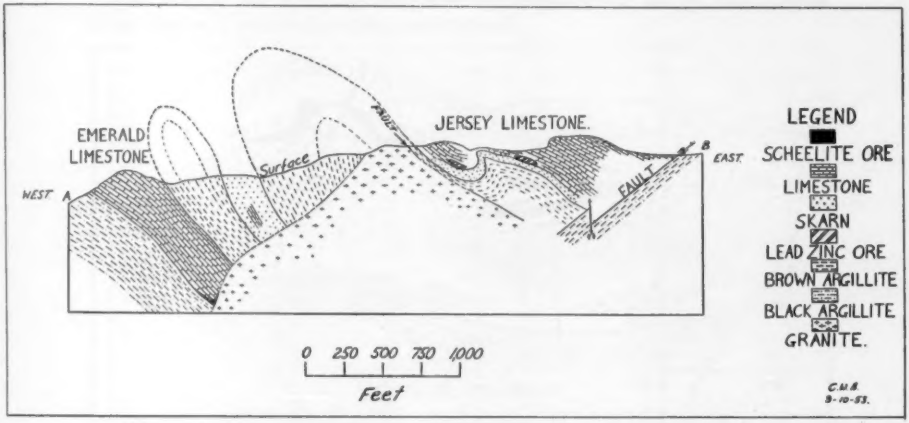


FIG. 3. Diagrammatic cross-section along line AB on Fig. 2, illustrating overfolding of strata.

Several minor post mineral faults with displacements of 10 to 60 feet and a north-west strike cut the ore zone. The movement in most cases is downward to the east, but one is reversed. (Fig. 3.)

## THE ORE ZONE

The ore occurs in a dolomitized zone at the base of the Jersey limestone in the upper limb of the main regional overturned fold.

The dolomitized zone and the underlying rocks are folded into north-south trending folds that plunge at about 12 degrees to the south. These folds are presumably drags on the main regional overturned fold. The ore occurs as a replacement in the troughs and on the limbs of the folds, the thickness and grade of ore diminishing on the crests. The zone can be traced

for nearly 7,000 feet along the plunge. The maximum mineralized width is 1,500 feet.

Stoping thickness varies from 6 to 80 feet. The zone contains on an average 850 tons of ore per foot of plunge length.

*Mineralogy.*—The mineralogy is simple. Fine-grained sphalerite and galena are the ore minerals. The sphalerite varies from light yellow to black. The lighter varieties contain more cadmium than the dark. The latter probably owes its color to manganese as both varieties contain about 1 percent iron.

Gangue minerals are dolomite and calcite as well as un-replaced limestone. Iron sulphides, pyrite and minor pyrrhotite, are present up to 6 percent in the ore. Very minor constituents are quartz, muscovite, chlorite, tremolite, wollastonite, olivine, serpentine, and some argillaceous material. Muscovite and chlorite appear to be associated with the sphalerite and appear as in-

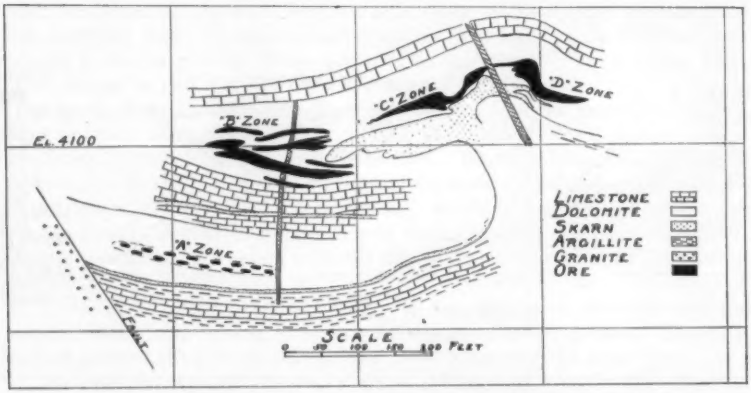


Fig. 4. Diagrammatic cross-section east-west looking north.

clusions in it. Sphalerite replaces the carbonates and silicates and is the same age as the iron sulphides. The galena appears to be later than the sphalerite.

*Ore Controls.*—The primary control of ore deposition is obviously folding. For purposes of mining, the ore has been divided into four zones each of which gives continuous stoping ground along the plunge and maintains its position in relation to one or other of the two main folds at present recognized.

The A zone follows the westerly of the two folds. This fold has an amplitude of about 60 feet and is overturned to the west. It can be seen in Figures 5 and 6. It dies out to the south and the ore fades out to low-grade mineralization as can be seen in Figure 4. It has been followed for over 1,200 feet in the mine workings, and may possibly be the control of the high-grade lead ore produced from the Emerald claim in the early days. High-grade ore occurs on the nose and within the overfold. On the west of the fold the dolomite zone and the ore are thick, but they feather out about 200 feet from

the fold. To the east, a narrow band of ore extends for about 200 feet, gradually decreasing in grade away from the fold, and with an increase in pyrite and decrease in zinc content it becomes uncommercial. The fold is best recognized by the skarn zone, for within the limestone there is no recognizable marker. The folds appear to die out in the limestone, the movement having been taken up by flowage. At the apex of the fold the ore is in contact with the skarn and for some distance to the west a narrow band of high-grade galena follows the skarn dolomite contact. To the east of the fold the ore leaves the skarn and both the hanging and footwall of the ore are dolomite.

The B, C, and D zones are associated with a fold to the east of the A zone fold. The greater amplitude of this fold causes the B zone to be about 80 feet higher than the A zone. The B and C zones are on the west of the fold and they die out as the intensity of the folding dies out to the north. As can be seen from Figures 4 to 6, the greatest development of the B and C zones is on Figure 1, where the fold is overturned.

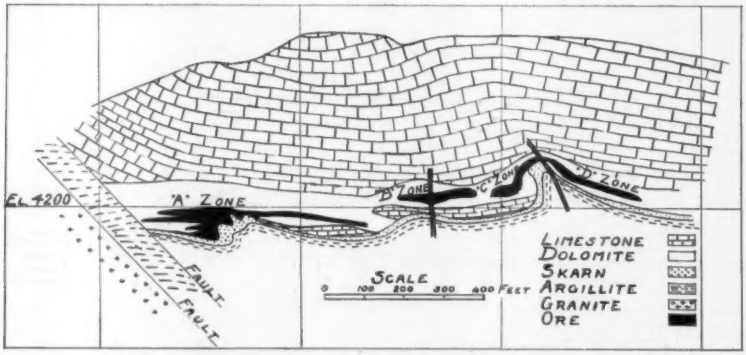


FIG. 5. Diagrammatic cross-section east-west looking north.

The D zone is on the east flank of the fold and appears to extend unbroken for 7,000 feet even though the fold flattens to a gentle anticline to the north. (Fig. 6.)

In the A and B zones the ore is mainly a replacement of the banding in the limestone. In the C and D zones much of the ore is a replacement of a breccia and considerable minor pre-mineral faulting exists.

The lead-zinc ratio is higher in the A zone, being about 3 lead to 5 zinc, but in the D zone the ratio is about 1 to 6. Minor drags in the main folds exercise the same control over deposition as the main folds.

The distribution of deposits of this type in the district is interesting. The outcrop of the limestone wherever seen is repeated, the eastern outcrop being right side up whereas the western is overturned. In the fourteen miles where these beds occur the right-side-up limb is known to contain nine orebodies, which together at a very minimum must contain ten million tons of

ore. The overturned limb, which is exposed for an equal length, contains hardly a prospect. This fact is difficult to explain but is probably due to structure. The most competent beds in the series are the quartzites stratigraphically below the limestone. These now occupy the center of the fold and are the footwall of the upper limb and the hangingwall of the overturned limb. The upper bed riding over the quartzite during the overfolding could have suffered the deformation that evidently controls the ore, while the overturned limb resting on less competent strata remained comparatively undisturbed.

### ORIGIN OF THE MINERALIZATION

The proximity of granite to the ore and the undoubted association of the scheelite mineralization on the property with the granite have led to the suggestion that the lead-zinc mineralization may be a low temperature phase of the same event.

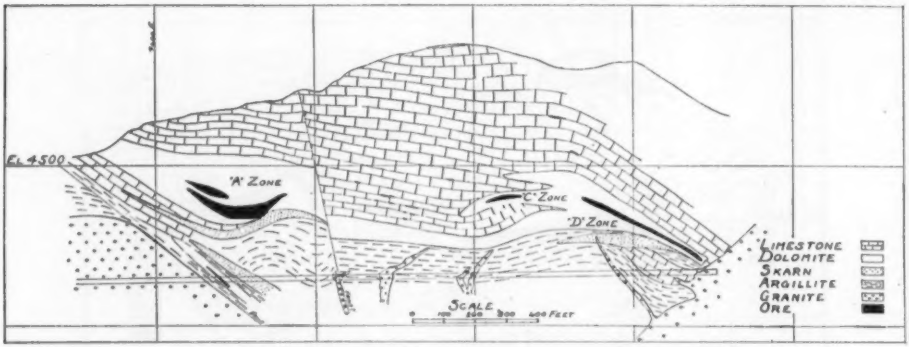


FIG. 6. Diagrammatic cross-section east-west looking north.

So many geologists have had to postulate a mythical intrusive as the source of their particular orebody that it almost seems wasteful to reject the granite as the source of the ore in this case. However the proximity of the granite to the ore may be fortuitous. The orebody is of a type of world-wide distribution characterized by dolomitized limestone host rock, iron-free sphalerite, absence of silver, and presence of cadmium. These deposits are typically far removed spatially from intrusives. The Jersey deposit is one of several in the district of the same type, in the same limb of the same fold in the same limestone bed. The other deposits are a matter of miles from the nearest granite outcrop. The proximity of granite is obviously not essential to the formation of this deposit.

A knowledge of the respective ages of the ore and the skarn might throw some light on the question but no relationship has been seen to fix their respective ages. Both must be post folding, and the lack of obvious metamorphism of the ore would suggest that it is younger than the skarn.

The association of zinc and scheelite in tactite deposits is fairly common. The scheelite ore on the property contains no zinc, which suggests that solutions from the granite contained no zinc.

Some samples of the granite and of the argillite stratigraphically above the limestone have been assayed by the dithizone method for traces of zinc. Insufficient work has been done to be conclusive but the results may be worth mentioning. All samples of granite ran less than 10 parts per million, but some argillite ran well over 100 parts per million. The zinc in the argillite could either be introduced from the same source as the zinc in the ore, or be an original constituent. If it is introduced, the solutions must have concentrated the metal in the orebody and disseminated it through the argillite, which would seem improbable. If it is an original constituent of the sediments it is a possible source of the zinc in the ore, concentrated by meteoric or other water.

CANADIAN EXPLORATION LTD.,
SALMO, B. C., CANADA,
*Dec. 2, 1953*

# DIRECTION OF FLOW OF LATE STAGE SOLUTIONS IN THE LAMAQUE NO. 6 VEIN

F. GORDON SMITH

ABSTRACT

Quartz from the No. 6 vein of the Lamaque gold mine, Bourlamaque, Quebec, decrepitates when heated, beginning at 80° to 124° C. The measured decrepitation temperatures, when plotted in the plane of the vein, can be contoured in a simple manner. The lower values are near the central part of the vein, where it crosses the principal granodiorite-greenstone contact, and the higher values are around the outer limits of ore in the vein. High grade ore specimens have a relatively rapid rate of decrepitation, low grade specimens have a relatively slow rate. Making the assumptions that the measured decrepitation is due to filling of secondary liquid inclusions trapped during the stage of gold deposition, and that the measured variation of decrepitation is due to variation of pressure during that stage, the contoured data are taken to mean that the later gold-bearing solutions entered the quartz vein at the principal wall rock contact and moved up and down the dip, depositing gold during, and possibly due to, the drop in pressure.

## INTRODUCTION

Quartz from gold-bearing veins in the Canadian Shield commonly contains visible secondary liquid inclusions, which cause decrepitation when heated above the temperature at which they become filled by the liquid phase (3, 4, 5, 6, 7). The decrepitation temperatures are quite low, from 80° to 200° C, and show systematic variations horizontally along the Kirkland-Val d'Or belt, and vertically in several deep mines in the same region. The interesting question of relation between the low temperature decrepitation and ore structures, qualitatively and quantitatively, suggested itself at this stage of the work.

Several lines of reconnaissance experiments indicated that some relationships between low temperature decrepitation and gold ore exist in the gold camps, but also that the relationships may not be simple. Decrepitation of specimens obtained over a considerable extent of one vein with simple associated structure would provide useful data on the relationships. Some of the veins in the Lamaque mine at Bourlamaque, Quebec, satisfy the simple structure requirements and it had been determined that ore quartz from this mine decrepitates vigorously. Dr. D. L. H. Forbes, president of Lamaque Mining Company, kindly permitted a study of the No. 6 vein and authorized publication of the results. Mr. J. C. Perry, manager, and Dr. R. G. Hoiles, geologist, facilitated the collection of specimens and the transcription of mining data.

The geology of the Lamaque mine was discussed by Wilson (8), and Figure 1 of this paper (p. 887) shows the position of the No. 6 vein in relation to the zoned granodiorite-diorite plug and country greenstone. In brief, the

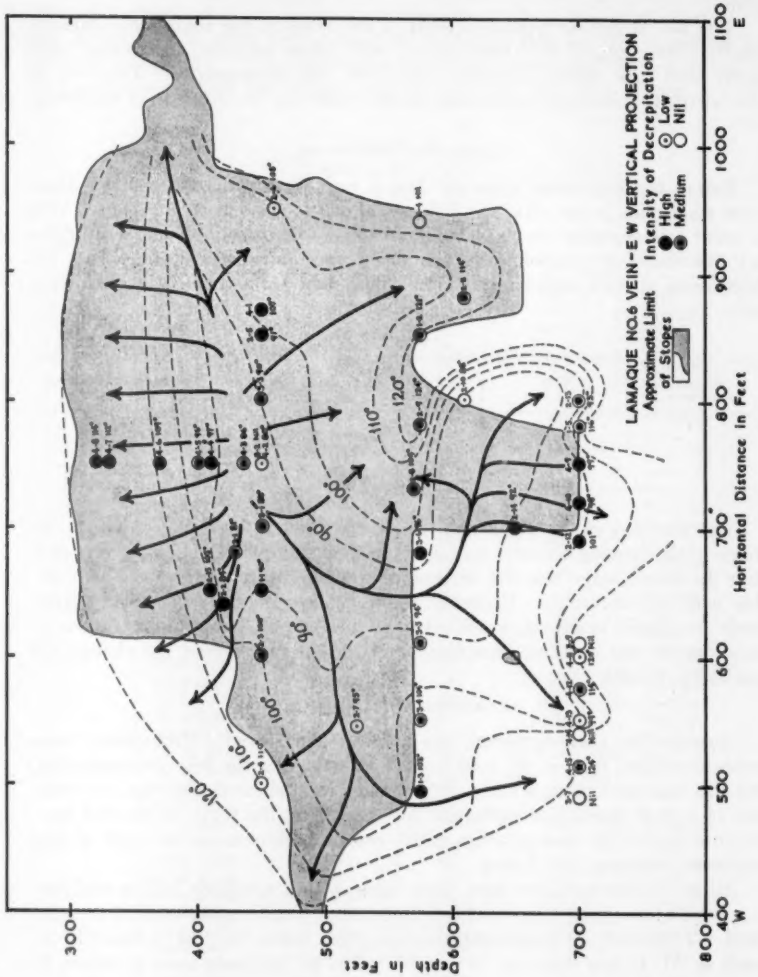
LAMAQUE NO.6 VEIN - E W VERTICAL PROJECTION
Approximate Limit of Slopes
Intensity of Decrepitation
High
Medium
Low
Nil
Depth in Feet
Horizontal Distance in Feet
W
E
300
400
500
600
700
800
400
500
600
700
800
900
1000
1100
80°
90°
100°
110°
120°

FIG. 1

vein dips in opposite sense to the plunge of the plug, and crosses the hanging wall of the principal contact at a large angle, as do a number of other similar veins.

The No. 6 vein is typical of most of the veins in the mine, and contains mostly coarse glassy to white quartz, with some ankerite, tourmaline, and pyrite, and rare calcite, scheelite, anhydrite, and chalcopyrite. The vein is now virtually mined out, and some stopes could not be entered for sampling.

## SAMPLING PROCEDURE

Before the specimens from the No. 6 vein were collected, a series from three wide veins in the mine was collected at one-foot intervals across each vein in order to determine the probable variations of decrepitation temperature at any one sampling position. No significant variations were found across the three veins at each sampling position. The data are shown in the following table.

TABLE 1

| No. of specimens | Vein No. | Level No. | Section No. | Decrepitation temp. and variation |
|---|---|---|---|---|
| 7 | 1 | 300 | 76 | 88±4°C |
| 9 | 13 | 825 | 29 | 107±3 |
| 3 | 35 | 2900 | 44 | 70±1 |

The sampling of the No. 6 vein was carried out in four stages, with a decrease in the spacing between specimens in each successive stage. It was only after the fourth stage that the decrepitation temperature values were contourable with any certainty. Probably additional specimens, especially between levels in certain positions, would change the over-all quantitative results to some degree, but it seems reasonably certain that they would not change the qualitative results.

## DECREPITATION METHOD

Quartz from each specimen was crushed and sieved. Preliminary tests having indicated that − 40 + 80 mesh material gives the best decrepigraphs, this size was used in each run. Preliminary tests showed also that the presence of a small amount of carbonate does not affect the shape of the low temperature part of the decrepitation of this material, eliminating the need of acid treatment, washing and drying.

All of the decrepitation runs were made with a specimen holder and furnace which have since been modified, and before a calibration method was devised. Therefore, all temperature values given below may be in error by as much as 20° C, but they may be considered to be relatively more accurate, to about ± 5° C.

The decrepitation temperatures given below are those at which there is a second order positive discontinuity in rate of decrepitation during heating of the specimen. The values were found by interpolating between temperature fiducial marks on a rate-time recording on a paper chart.

### DECREPITATION DATA AND DISCUSSION

During the work, it became evident that quartz from high-grade parts of the vein decrepitates much more rapidly than quartz from low-grade parts, and that barren quartz often decrepitates at too low a rate for the apparatus to integrate and record. This relation was made semi-quantitative by separating the maximum rates of low temperature decrepitation into four groups of rela-

TABLE 2

LAMAQUE NO. 2 VEIN

| Specimen Number | Location of specimen | | | Decrepitation results | |
|---|---|---|---|---|---|
| | Drift or stope | Depth | Section | Temperature | Relative rate |
| 1–1 | 45–6 Drift | 450 | 65 | 90° C | High |
| 1–2 | 60–6 Drift | 575 | 85 | 121° | Medium |
| 1–3 | 60–6 Drift | 575 | 49.5 | 103° | High |
| 1–4 | 60–6 Drift | 575 | 94 | — | Nil |
| 1–5 | 70–6 Drift | 700 | 78 | 116° | Medium |
| 2–1 | 45–6 N Stope | 430 | 68 | 81° | Medium |
| 2–2 | 45–6 N Stope | 420 | 64 | 84° | High |
| 2–3 | 45–6 Drift | 450 | 60 | 100° | Medium |
| 2–4 | 45–6 Drift | 450 | 50 | 110° | Low |
| 2–5 | 45–6 Drift | 450 | 85 | 91° | High |
| 2–6 | 60–6 Stope | 460 | 95 | 108° | Low |
| 2–7 | 60–6 Sub-Level | 525 | 54.5 | 95° | Low |
| 2–8 | 60–6 Drift | 570 | 73 | 104° | Medium |
| 2–9 | 60–6 Drift | 575 | 78 | 124° | Medium |
| 2–10 | 70–6 Stope | 610 | 80 | 88° | Low |
| 2–11 | 70–E Drift | 610 | 88 | 114° | Medium |
| 2–12 | 70–6 Drift | 700 | 69 | 101° | High |
| 2–13 | 70–6 Drift | 700 | 80 | 93° | Medium |
| 2–14 | 70–6 Stope | 650 | 70 | 92° | High |
| 2–15 | 45–6 N Stope | 410 | 65 | 105° | High |
| 3–1 | 45–6 Drift | 450 | 70 | 83° | Medium |
| 3–2 | 45–6 Drift | 450 | 75 | — | Nil (See 4–2) |
| 3–3 | 45–6 Drift | 450 | 80 | 90° | Medium |
| 3–4 | 60–6 Drift | 575 | 55 | 104° | Medium |
| 3–5 | 60–6 Drift | 575 | 61 | 94° | Medium |
| 3–6 | 60–6 Drift | 575 | 68 | 96° | High |
| 3–7 | 70–14 Dritt | 700 | 49 | — | Nil |
| 3–9 | 70–14 Drift | 700 | 61 | — | Nil |
| 4–1 | 45–6 Drift | 450 | 87 | 107° | High |
| 4–2 | 45–6 Drift | 450 | 75 | 80° | Low |
| 4–3 | 45–6 Stope | 435 | 75 | 86° | Medium |
| 4–4 | 45–6 Stope | 410 | 75 | 97° | High |
| 4–5 | 45–6 Stope | 400 | 75 | 96° | Medium |
| 4–6 | 45–6 Stope | 370 | 75 | 109° | High |
| 4–7 | 45–6 Stope | 330 | 75 | 112° | High |
| 4–8 | 45–6 Stope | 320 | 75 | 114° | High |
| 4–9 | 70–6 Drift | 700 | 75 | 99° | High |
| 4–10 | 70–6 Drift | 700 | 72 | 98° | High |
| 4–11 | 70–14 Drift | 700 | 60 | 120° | Low |
| 4–12 | 70–14 Drift | 700 | 57.5 | 114° | Medium |
| 4–13 | 70–14 Drift | 700 | 55 | 99° | Low |
| 4–14 | 70–14 Drift | 700 | 54 | — | Nil |
| 4–15 | 70–14 Drift | 700 | 51.5 | 124° | Medium |
| Averages | | 534 | | 101° C | Medium–High |

tive values, and averaging the gold content of the vein near the position of the specimens in each group. The group with high rate had an average of 7.6 dwt./ton, moderate rate, 6.1 dwt./ton, low rate, 5.6 dwt./ton, and nil, 3.0 dwt./ton.

The decrepitation temperatures of quartz from 43 positions in the No. 6 vein are given below in Table 2. These values are shown in Figure 1, plotted in the plane of the vein, and contoured as isotherms. The probable interpolation and extrapolation of the decrepitation isotherms through parts of the vein not sampled, were controlled by the facts that almost all of the quartz of this vein was of ore grade, and the mining stopped near the limits of quartz, combined with the assumption that the country rock at the time of gold mineralization was not nearly as permeable as the quartz vein.

The isotherms in Figure 1 show a cluster of lowest temperature values near the 450 foot level, but slightly higher, but still low values, appear to lead off from that area in several directions. The decrepitation temperatures increase, but the maximum rates decrease, away from the central part of the vein. There is a suggestion that the limit of ore coincides approximately with the 120° isotherm.

The variation of decrepitation temperature is most likely due to variation of degree of filling of fluid inclusions in the quartz, which in turn may be due to variation of temperature and/or pressure during deposition or reworking of the quartz. It was concluded in two previous studies (4, 5) that variations of pressure were more important than variations of temperature, but this matter needs reanalysis. However, making such an assumption in this case, the directions of decrepitation isotherms become directions of isobars during deposition or reworking of the quartz, and lines with directional sense perpendicular to these isobars give the direction of flow of the solutions (Fig. 1).

The pressure drop corresponding to a rise of decrepitation temperature from 85° to 120° C is approximately 6,000 pounds per square inch. The maximum gradient of this calculated pressure difference in the plane of this vein is 30 pounds per square inch per foot, or about 2 atmospheres per foot. This is a very large pressure gradient, which could be maintained with either improbable volumes of solution in open fissures, or with the passage of the solution through minute secondary openings in the quartz. Planes of secondary liquid inclusions representing healed cracks are very abundant in this quartz, as in most auriferous quartz. Therefore, the second explanation is chosen as being more probable.

The vein, with decrepitation isotherms and derived lines of direction of flow of mineralizing solutions, is shown with the principal geological contact in oblique projection (Fig. 2). It will be noted that the place of maximum pressure (lowest decrepitation temperature) is where the vein crosses the contact between the stock and the surrounding greenstone, near the 450-foot level. Therefore, this hanging wall contact of the stock can be postulated to be the structural control over the ascent of at least some of the mineralizing solutions. Also, since there is a relation between the low-temperature decrepitation of this vein and its gold content, the contact can be postulated to be the principal channelway for the gold mineralization.

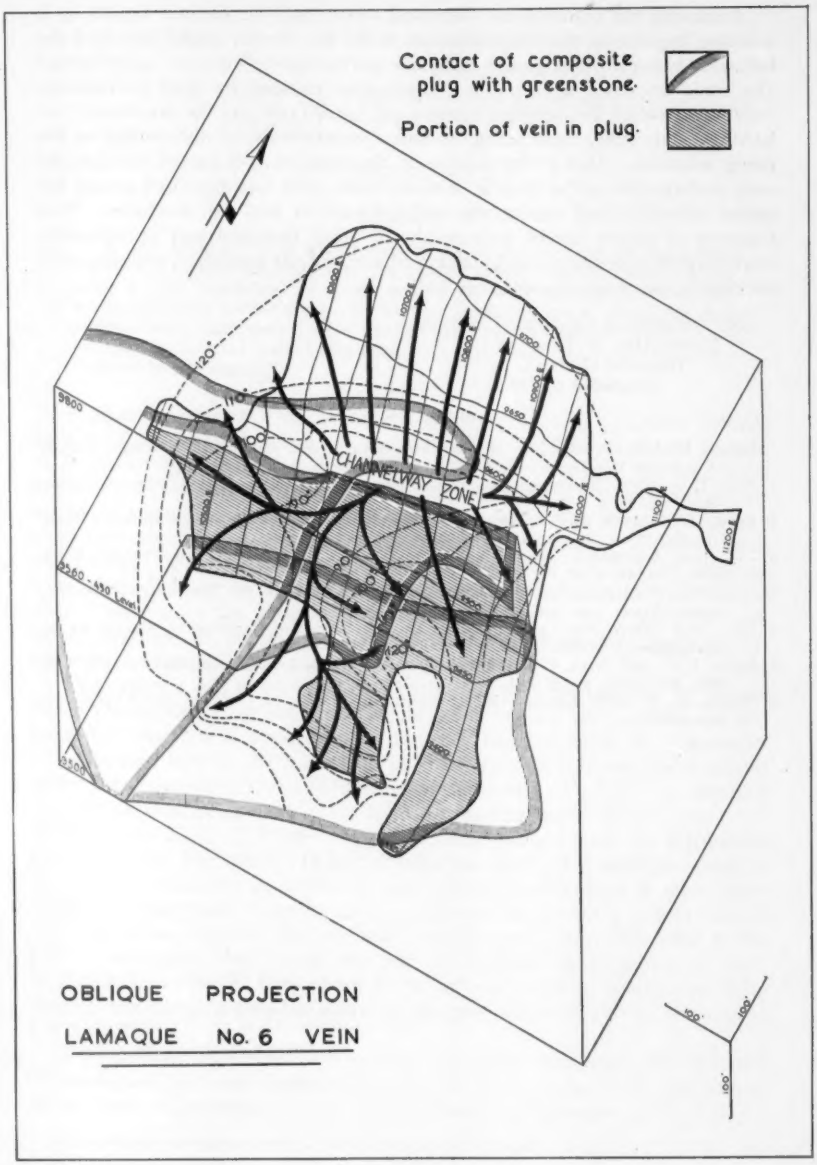
Contact of composite plug with greenstone.
Portion of vein in plug.
CHANNELWAY ZONE
OBLIQUE PROJECTION
LAMAQUE No. 6 VEIN

FIG. 2

Retaining the assumptions discussed above, and the derived results as a working hypothesis, the mineralization of the No. 6 vein might have had the following history. The quartz-carbonate-pyrite-tourmaline veins were formed (by some unknown agency), and later were crushed by fault movements. Solutions rose up the principal contact and spread out into the brecciated (dilated) quartz veins, these acting as minor channelways of distribution of the rising solutions. Due to the changes in the solution as it passed through the vein, perhaps due to the drop in pressure itself, gold was deposited among the earlier minerals, and quartz was redistributed to heal the fractures. This sequence of events agrees with results of other inclusion and decrepitation work on gold deposits of the Canadian Shield, not yet published, and also with the clearly late stage deposition of gold (1).

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*December 9, 1953*

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# GENESIS OF THE WITWATERSRAND GOLD–URANIUM DEPOSITS

STANKO MIHOLIĆ

ABSTRACT

A new explanation of the genesis of the Witwatersrand gold-uranium deposits is tentatively suggested: In marine gravel deposits along a steep coast a rich vegetation of uranium concentrating organisms developed under anaerobic conditions giving rise to the formation of thucholite and pyrite. At a later period gold was reduced by the organic matter from percolating thermal waters that contained it in ionic form, and was accumulated in the deposits.

To explain the genesis of the Witwatersrand gold deposits two main theories have been put forward. The one considers those deposits as placer deposits of Archaean age, while the other supposes the deposition of the gold from hydrothermal solutions. The recent discovery that the deposits contain remarkable amounts of uranium in a close relationship with the gold but even more persistent in the deposits has complicated the question of their genesis still further. C. F. Davidson (1)[1] has rightly pointed out that the presence of uraninite is likely to rule out the possibility that the deposits originated as placers because of the great friability and solubility of the uraninite, which would preclude its accumulation in placers. He tentatively suggested the hydrothermal origin of the deposits of both elements.

The deposits are, however, closely connected with the presence of carbon, which cannot be of hydrothermal origin. To explain the presence of carbonaceous material in some uranium minerals like thucholite W. Vernadsky (2) supposed it to be the result of a polymerization of gaseous hydrocarbons under the influence of the α-radiation from uranium. E. Grip (3) accepted this explanation for the thucholite from the Boliden mine and so does C. F. Davidson and S. H. U. Bowie (4) for the same mineral from the Witwatersrand mines and elsewhere. In fact E. Grip has shown that methane occurs in the deeper levels of the Boliden mine, and methane accumulates in some mines of the Witwatersrand region in such quantities as to present a serious hazard. C. F. Davidson connects this methane with the coal seams belonging to the Karroo formation which occur, however, on a much higher geological level. In the Boliden mine E. Grip points to horizons of graphitic schist underlying the ore deposits as a possible source of the gas composed chiefly of methane (59.6–68.8%).

That methane and other hydrocarbons can polymerize under the influence of α-radiation has been shown experimentally by S. C. Lind (5) and others. In all those experiments considerable amounts of hydrogen (13.9–37.8%)

[1] Numbers in parentheses refer to References at end of paper.

were formed which are lacking in the natural occurrences cited above which contain only 0.0–1.0 percent of hydrogen. This could perhaps be explained with loss through diffusion, but as the gases contain remarkable amounts of helium (2.3–5.4%), one would expect that helium would be lost through diffusion even quicker than hydrogen.

If the explanation of the genesis of solid carbonaceous matter through polymerization of gaseous hydrocarbons under the influence of α-radiation might perhaps be expedient for minerals like thucholite and similar minerals with a high content of uranium or thorium, it is much less appropriate for material low in uranium, but high in carbon. Recently a number of shales has been analyzed containing remarkable amounts of uranium so as to form in some cases uranium ore (e.g. the Cambrian alum shales of Sweden). And yet their carbon content is so high that Vernadsky's hypothesis is hardly applicable. There is a very close connection between the uranium and carbon content as shown by R. F. Beers and C. Goodman (6) which cannot be fortuitous. Some recent black muds contain up to 60 ppm of uranium (7). Here time would be lacking for the radiogenic origin of the carbonaceous matter contained in them. Therefore, another explanation for the genesis of uranium containing carbonaceous matter has to be sought.

The author (8) has investigated a number of mineral and thermal waters in Jugoslavia and found that waters issuing from sediments belonging to certain geological periods (Carboniferous and Cretaceous) show an increased radioactivity. Later investigations have shown (9) that the same seems to be the case with waters issuing from paragenesis of the late Archaean.

To explain this phenomenon the author has suggested a biogenetic accumulation of uranium by specific microorganisms, living under anaerobic conditions, which flourished in certain geological periods but have even at present not disappeared altogether. They might use the radioactive energy of uranium (and other radioactive elements) in their life processes. Those uranium accumulating organisms seem to belong to the oldest, if not the first organisms that appeared on earth, and were particularly numerous in the late Archaean as a great deal of carbonaceous matter from that period contains remarkable amounts of uranium. No uranium determination, however, has yet been made on *Corycium enigmaticum* from the late Archaean of Finland that represents what is presumed to be the oldest organism so far described (10).

Later the activities of some iron and manganese bacteria gave rise similarly to deposits of iron and manganese ore some of which are of economic significance, and the activity of hydrogen sulfide-oxidizing and of the little known sulphate-reducing bacteria led to the formation of all the main sulphur deposits. Some diatoms (e.g. *Nitschia Palea*) feed on kaolin and liberate silicic acid (11), using thus the energy freed in the decomposition of this endothermic compound, and silicate degrading silicic bacteria have recently been found in some mines and thermal waters.

On the basis of the above moments a new hypothesis for the genesis of the Witwatersrand deposits is tentatively put forward.

The conglomerates are marine shore deposits of late Archaean age. A rich vegetation of uranium concentrating organisms developed in them and

accumulated uranium the more so, as natural waters very likely then contained uranium in a somewhat greater concentration than at present. The presence of pyrite would point to anaerobic conditions prevailing at the time of the formation of the deposits. E. T. Mellor (12) suggested that the gravel represents large delta deposits. If it is supposed that those deposits were formed in fairly deep water containing hydrogen sulfide along a steep coast, there would be conditions that would correspond to the facts observed. Similar conditions prevail, even to-day, in some Norwegian fiords where deposition of black mud containing iron sulfide and accumulation of uranium are still going on as shown by K. M. Strøm (7) and also on the bottom of the Black Sea along the Caucasus range, where mountain streams deposit their gravel in the sea at considerable depths, and where the water at a depth of 150 m contains appreciable amounts of hydrogen sulfide.

At a somewhat later period thermal waters containing gold in ionic form passed through those deposits and the gold ions were reduced to metal by the organic matter and accumulated in it. The organic matter quite naturally underwent a carbonization process that would account for the methane and other gaseous hydrocarbons present in the Boliden mine and at Witwatersrand. That the deposition of gold is also connected with the presence of carbon is shown by the rich Blyvooruitsicht seam in the Far West Rand, whose thickness rarely reaches as much as half an inch, but which has a great horizontal extension. Radiometric examinations of drill-holes in the Witwatersrand district by D. J. Simpson (13) have shown that barren gravel deposits alternate with gravel deposits containing both gold and uranium, as well as carbon. If it were the case of simple deposition from ascending mineralized thermal waters, one would expect all the gravel deposits, as well as the sands, to contain both elements, as there is no chemical difference in gravel and sand layers to explain such alternations that occur in metasomatic deposits of some other minerals (e.g. galena replacing limestone but not argilaceous schist). This hypothesis agrees well with the observed facts: pitchblende and pyrite are later than pebbles and replace them partly in some cases, and gold is later than pyrite.

There are, however, some features that at the first glance appear to disagree with the proposed hypothesis of the biogenic origin of the thucholite.

The first is the occurrence of thucholite in pegmatite dikes. But in all cases known to the author, the mineral was embedded in the pegmatitic material as a distinctly foreign body that could have been picked up at lower levels from biogene deposits and carried up by ascending waters.

The other feature is the pseudomorphoses of thucholite after uraninite, and even after tourmaline. W. Vernadsky (2) showed how large cubes of uraninite are transformed into carbonaceous matter, beginning from the surface, while the inner portions still preserve an intact core of uraninite. But mineragraphic investigations by C. F. Davidson and S. H. U. Bowie (4) have shown that recrystallization has taken place in the mineral, and that radiogenic lead is also separating in blebs of galena from the amorphous mass. It is, therefore, permitted to conclude that the same might be the case with uraninite and that the so-called pseudomorphoses of thucholite are in fact

crystals of uraninite that are separating from the amorphous mass and taking shape.

10 Svibovac,
Zagreb, Croatia,
*Dec. 20, 1953*

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# DISCUSSION

## *WHAT KILLED CORYCIUM ENIGMATICUM?*

*Sir:* In a recent communication (1), my friend, Dr. Harmon Craig of the Institute for Nuclear Studies of the University of Chicago, expressed the wish that the readers of review articles should be informed, by suitable means, as to whether or not the reviewer was adequately acquainted with the field of his review to be able to make a critical evaluation of the results discussed. If he was, his review might be labeled a critical review; in the opposite instance it was to be called a clerical review.

This, a highly commendable suggestion, was precipitated by a review article in the field of isotope geology by Jensen (2). A statement referring to my previous investigation of the origin of Precambrian carbon (3) had raised Craig's ire, and he regretted that Jensen added a certain implied validity to my original thesis by stating it as a general fact in his own terms. To be consistent with the overall tone of the review, Craig continued, the thesis would better have been referred directly to me and cited as my personal opinion. Craig's thesis implies that in Jensen's review the distinction between clerical treatment and critical treatment of the subject matter was not made sufficiently clear. Craig expressed the belief that what is meant to be a clerical review may sometimes inadvertently become an incompetent critical review that misinforms the general reader.

I have carefully studied Jensen's paper (2). Even though I do not consider myself such a highly active worker in the field of isotope geology as Craig undoubtedly is, it appears to me that Jensen's review is very readable and should well fulfill its stated purpose of calling attention to the many possible applications of isotope research to economic geology. His literature coverage, however, is incomplete, and his bibliography contains mostly papers published in North American journals. The economic geologist desiring to obtain further information about isotope geology will do well to consult the complete review of Ingerson (4).

I am afraid that in his eagerness to make *Corycium enigmaticum* a defunct species, Craig has not studied Jensen's paper carefully enough to realize that Jensen actually has written a critical review. Thus, he (2, p. 168) warns the reader that it is generally dangerous and often misleading to combine isotopic abundance data obtained by means of different mass spectrometers because of systematic differences in the instruments, unless a standard sample is used to correlate the ratios. Furthermore, he (2, p. 175) reminds his readers about the possible inadequate precision of some measured $K^{39}/K^{41}$ ratios. Finally, referring to *Corycium enigmaticum*, Jensen (2, p. 167), by saying that I had shown that it "is probably the oldest valid fossil," certainly

takes a less emphatic and a more conservative viewpoint than I did in my original paper (3). I am unable to find in this modified statement the meaning attributed thereto by Craig, viz., that Jensen stated my thesis as a general fact.

To return now to what Craig calls the nonindicative properties of isotopes, he claims that the validity, in principle, of using the isotopic constitution of carbon as a criterion of its biogenic or nonbiogenic origin fails in the case of the *Corycium*. I have discussed this conclusion at length elsewhere (5) on the basis of Craig's earlier paper (6). Therefore, it is sufficient here to point out that Craig's thesis is not infallible. Because the fractionation factors for isotopic exchange reactions involving carbon in the form of graphite cannot be calculated, Craig concludes that it is impossible to know that graphite enriched in $C^{12}$ cannot be formed in some way from carbonate enriched in $C^{13}$ or from any other inorganic carbon, even though one would know the temperatures and specific reactions that must have obtained during the formation of graphite. He, however, fails to present any evidence indicating that a graphite deposit, or graphite disseminated in a schist, was formed under equilibrium conditions. To be sure, when the light carbon isotope became concentrated in Precambrian clays and muds in biogenic matter, nobody did ask whether the process took place under equilibrium conditions and whether the equilibrium constant was known. Isotope-exchange equilibria definitely cannot be applied to the problems of graphite formation. Certainly, one cannot tell Mother Nature to be a good girl and to behave according to rules established in the laboratory. As Craig says, even though one would know the equilibrium constants one still could not exclude nonequilibrium processes. This statement is correct when one remembers that natural processes, in fact, are nonequilibrium processes.

Craig says that if my conclusion were correct one could apply the criterion to the origin of any graphite deposit. But, inasmuch as carbon in igneous rocks lies within the biogenic range, he feels that the argument becomes even more hopeless. He says that if one reasons that specific circumstances *in casu* rule out all other manners of origin, then one is simply reverting back to geologic evidence, and there is no need even to discuss the isotopic constitution. I am afraid that geologists who are accustomed to collecting evidence from many, not one, sources and to carefully considering a multitude of different and not necessarily related facts will find it difficult to agree with Craig's opinion. It would, of course, simplify the matter very much if a geologist could consider a rock or a mineral just another reagent bottle from the laboratory shelf as a chemist is apt to do. When dealing with geologic material one must, however, very carefully consider its natural surroundings, and no piece of evidence must be cast aside that may prove helpful in deciphering the origin. Consequently, one should hesitate to accept conclusions that rest solely on chemical theory and evidence. With particular reference to the *Corycium*, there is geologic (3), geochemical (3, 7), and isotopic (3, 5) evidence indicating its biogenic origin.

Nobody, of course, can claim that it is always possible to decide whether the carbon in a rock is of biogenic or nonbiogenic origin. But if there exists no contradicting geologic evidence, one may conclude that carbon in shales,

slates, and schists of any age is biogenic if its isotopic constitution falls within the biogenic range.

The *Corycium* has duly finished its course of life; *requiescat in pace.* It died no less than 1,500 million years ago, definitely not on June 12, 1953, as Craig, a self-appointed coroner, wants one to believe after having disinterred, once more, its black carbon remains for autopsy. What killed it was certainly not a shot of equilibrated carbon isotopes from an exchange reaction involving graphite administered by Dr. Craig in his laboratory. It appears proper to conclude this discussion with a quotation from Jensen (2, p. 175): "There is not only a great need for a multitude of high precision isotopic abundancy ratios, but a great need of accurate descriptions by geologists of the geologic occurrence of specimens from which ratios are determined"; and with another quotation from Craig (1, p. 602): "since no one is infallible there will of course be occasional mistakes in both judgment and interpretation." One certainly agrees with these statements.

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*February 15, 1954*

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# REVIEWS

**Geologic Map of East Tennessee, with Explanatory Text.** Compiled by JOHN RODGERS. Pp. 168; pls. 15; figs. 7. Tennessee Division of Geology Bull. 58, pt. 2.

Between 1894 and 1907 most of east Tennessee was geologically mapped on the scale of 1/125,000 and presented in a series of U. S. Geological Survey folios. Thereafter not much additional mapping was done in this part of the State until the establishment of the Tennessee Valley Authority in 1933. At that time a series of planimetric maps, followed by topographic maps on the publication scale of 1/24,000, was initiated. Geologic mapping for dam sites in the 1930's was followed during and after World War II by intensive mapping in east Tennessee in connection with strategic minerals studies, particularly for manganese and zinc, but also in connection with ground water investigations. Thus a tremendous reservoir of detailed modern geologic mapping, some published, some unpublished, has accumulated in the last 20 years.

Rodgers has now brought all of this modern mapping together in summary form, as a cooperative undertaking of the Tennessee Division of Geology and the U. S. Geological Survey. The Tennessee Survey has given handsome publication to the work.

The heart of the contribution is the geologic maps, which are on the scale of 1/125,000 and are on a new planimetric base prepared especially for the purpose. The mapping is in 14 plates, each representing all or part of a 1/125,000 quadrangle; a 15th plate contains geologic cross sections. These have been published in a flat folio edition and also in a folded edition in an octavo box. The text is explanatory of the map, with discussions of the compilation procedures, the mapped units, the structural features of regional significance, and a discussion and listing of significant projects for future work in east Tennessee.

The reviewer has only one minor criticism of this publication. His personal preference is for more vivid colored inks for the patterns on the geologic maps, to make the regional grain of the country stand out clearly, rather than for pastel colors that blend together as do the colors on these maps.

The compiler rightly refers to the geologic map of east Tennessee as a progress report. Whereas considerable parts of the area covered are based on large-scale modern mapping, other large areas have no coverage except the early folio maps. In these areas Rodgers has done some reconnaissance and some photogeology. Of particular interest is the use he has made of modern soil maps of the U. S. Soil Conservation Service. In a nonglaciated region such as this, much of the geology can be successfully interpreted in a reconnaissance manner from the mapped soil units. In fact, geologists mapping in east Tennessee, particularly in the thick sequences of poorly exposed Cambrian and Ordovician dolomites and limestones, necessarily rely heavily on soil characteristics of the different formations to delineate boundaries. Some have even become so skilled in this technique that it is easier for them to identify a formation by the soil than by outcrops.

On the maps certain gross units have been given distinctive patterns, such as the "Knox group" or the "Conasauga group." In areas where thinner units such

as formations have been mapped within these groups, contacts are shown and are distinguished by the appropriate symbol but without a distinctive pattern. Thus the compilation and publication problems have been rendered more manageable, and the compiler has been able to show details where he had detailed data and to generalize where he did not.

The text provides an excellent summary of the regional geology of east Tennessee. Most space is devoted to the stratigraphy. Herein are described all of the formations shown on the maps, and controversial parts of the column are discussed at some length, particularly the complex and still imperfectly understood stratigraphy of the lower Middle Ordovician. Rodgers' thoughtful analysis of the problem of lower Middle Ordovician nomenclature and correlation in east Tennessee is well worth careful reading and consideration by all who have been working with this particularly difficult sequence of rocks in the Appalachian belt. He takes an intermediate and well-reasoned position between those who would cling to the old nomenclature for reasons of simplicity and those who would abandon all the old names and rename all the mappable units on the grounds that the early workers did not clearly recognize some of the facies changes of time-rock units and hence made some miscorrelations in east Tennessee and adjacent States.

Rodgers' "list of outstanding projects for future mapping in east Tennessee" is a particularly useful addition. No one is in a better position to compile such a list than one who has just struggled with the problems of resolving the discrepancies between contributions of individual geologists and of improvising in order to fill in little known areas of a regional map.

No more useful publications on the geology of the Southern Appalachians has appeared since Butts' compilation of a "Geologic Map of the Appalachian Valley of Virginia," and recent advances in cartography and stratigraphy make this superior to Butts' great contribution of 1933. It is greatly to be hoped that we may have more regional syntheses of geology. This one is of immeasurable value to all geologists working in or near east Tennessee and will be a standard reference work for many years.

RALPH E. MILLER

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.,
*May 6, 1954*

**Rocks and Mineral Deposits.** By PAUL NIGGLI. English translation by ROBERT L. PARKER. Pp. 572; figs. 331; tbls. 73. W. H. Freeman, San Francisco, 1954. Price, $12.00.

Professor Niggli's book, *Gesteine und Minerallagerstätten,* appeared in Basel in 1948. This volume is an English version of the original by Professor Parker. In the translation a few changes were made. New material has been introduced on crystal chemistry and on classification schemes. Other parts have been shortened, and the part in the original on geophysics has been omitted since this subject is so adequately treated in other publications in English. The original illustrations have been reproduced and where German words are contained in the text, English translations are given in the legends.

The book is divided into four parts, as follows: I, The Materials; II, The Fabric; III, Physical Chemical Principles Governing the Formation of Minerals and Mineral Products; IV, Basic Principles for the Systematic Classification of Rocks and Minerals.

The following chapter headings convey the general context of the book: Ele-

ments of Geochemistry; Elements of Crystal Chemistry; Simple Formulations of the Chief Minerals; Some Relationships Between the Chemical and the Mineralogical Composition of Rocks; The Mineral Assemblage; Structural Relations Among the Fabric Grains; Textural Relations Among the Fabric Grains; The Technical Properties of Mineral Aggregates and Their Connection with Mineralogical Composition and Fabric; Laws of the Stability and Coexistence of Minerals in Mineral Aggregates; Important Processes of Minerogenesis; Preparatory Stages of the Crystallization Processes; The Exogenetic Rocks and Mineral Deposits; The Endogenetic Rocks and Mineral Deposits.

The main approach to Part I is geochemical and crystal chemistry, as is also Part III. The classification of rocks is the former Niggli classification and that of ore deposits is the Niggli-Schneiderhöhn classification, which is not looked upon with favor in America. The parts dealing with crystallization processes will be found to be of much interest to students of ore deposits.

The title might indicate that the book deals equally with rocks and mineral deposits. Actually, it is almost entirely petrology, which was Niggli's love, with very little reference to mineral deposits except under crystallization and a brief statement on classification. The book is nicely printed and well illustrated. It is bound to become a reference work for petrologists.

**The Physical Chemistry of the Silicates.** By WILHELM EITEL. Pp. 1592; figs. 952. The University of Chicago Press, Chicago, 1954. Price, $30.00.

This new American edition of the well-known German text (1st ed. 1929, and 2d ed. 1941) will be a valuable source-book for mineralogists, petrologists, economic geologists, and ceramic engineers. Professor Eitel has assembled in one volume a vast amount of detailed, basic information on silicate chemistry that was originally scattered through the literature of the world.

The book is divided into five parts. Part one, "The States of the Silicates," consists of three chapters describing the crystalline state, the fused and glassy states, and colloids. Chapter one, "The Crystalline State," includes basic discussions of several subjects important to mineralogists and petrologists; these include the $SiO_4$ group and its tetrahedral arrangements, the special structures of the silicates and the minerals representing these structures, isomorphism and its effects on the physical properties of crystalline solutions (solid solutions), model structures for silicates, and the structure of clay minerals.

Chapter two, dealing with the fused and glassy states, will be important mainly to engineers, but sections on viscosity and diffusion in silicate melts have an important bearing on differentiation of magmas and so will be of interest to geologists. In chapter three, colloids in general are discussed; also colloidal solutions and sols, their electrostatic charges and their optical properties are described; sections on x-ray investigation and electron microscopy of colloids are included. The section on reactions of mixed silica-alumina gels in soil weathering is important in understanding the formation of laterites and bauxite. The first part of the chapter describes the clay-water system, including base exchange and the electrostatic theory of clay-water mixtures.

The second part of the book is concerned with fusion and polymorphic equilibria in dry silicate systems. Chapter one of this section includes, under general remarks on fusion and polymorphic phenomena, the measurement of fusion points, undercooling and crystallization, observations and theoretical deductions about polymorphic inversions, and methods of determining inversion points. The second

chapter describes the various silicate systems with the aid of many binary and ternary diagrams.

Part three consists of two chapters; the first deals with silicate systems that have volatile components and describes in detail the synthesis of silicates under hydrothermal conditions; the second describes the silicate hydrates of the zeolite and permutite group. Solid state reactions in general, and in ceramic bodies and hydraulic cement in particular, are discussed in part four. The last part is on silicate melts as industrial glasses and slags.

The book is well illustrated and well documented with many footnotes referring to papers in over 700 international periodicals. The system of numbered paragraphs and the various indexes, subject, mineral, chemical and author, help to make this book a quick guide to the extensive literature on the silicates.

FRANK G. LESURE

YALE UNIVERSITY,
NEW HAVEN, CONN.,
*May 10, 1954*

**Recollections of an Indian Geologist.** By RAMA RAO. Pp. 441; pls. 6. Mysore Geologists' Assoc., Bangalore, 1953.

Dr. Rama Rao, retired Director, Indian Bureau of Mines, and former Director of the Mysore Geological Department, has produced a very interesting autobiography that depicts the upbringing, education and training of an Indian geologist; his tours abroad; and the part he played in the development of Indian geology. More than that it is an intimate and fascinating story of life in an Indian village, in towns and in the Kolan gold camp. There is woven into the text stories of plague, of the process of education, of hunting tigers and elephants, of adventures of a young geologist, of hardships of a young Indian scientist in finding a job, and particularly of everyday life of the people of India, of which Westerners know so little. One follows also the development of geology in India.

If the book were available in America, it would be a good seller.

ALAN M. BATEMAN

**Out of the Earth.** By G. B. LANGFORD. Pp. 140; pls. 14; figs. 28; tbls. 3. University of Toronto Press, Toronto, 1954. Price, $3.50.

Those interested in the broader phases of the mineral industry would welcome more books of this type. This one, while it relates largely the mining industry of Canada, also covers much of broader interest pertaining to mineral industry as a whole. It is the outcome of a series of popular lectures delivered under the auspices of the University of Toronto dealing with different phases of mining by individuals versed in their respective fields. These include an opening chapter by Charles Camsell on the Romance of the Mining Industry in Canada, followed by chapters on the geology of mineral deposits, modern methods of prospecting, mining and processing of ores, the story of metals, mineral fuels, industrial minerals and rocks, financing a company, government services and the mineral industry, and a concluding chapter by V. C. Wansbrough on Canada and Her Mineral Industry. An appendix gives the mineral production of Canada from 1898 to 1952.

The author has woven the meat of these lectures into a very readable story in such simple language that everyone can understand it. The interested layman and the student of mining or geology will find in this book a story of minerals and metals and how they are won.

## BOOKS RECEIVED

FRANK G. LESURE

**U. S. Geological Survey—Washington, D. C., 1954.**

**Bull. 982-G. Geology of the Dover Magnetite District, Morris County, New Jersey.** PAUL K. SIMS. Pp. 245–305; pls. 5; figs. 8. *Description of petrology, structure, mineralogy of district.*

**Bull. 995-D. Geologic Investigation of the Boyerstown Magnetite Deposits in Pennsylvania.** H. E. HAWKES, HELMUTH WEDOW, AND J. R. BALSLEY. Pp. 135–149; pls. 5; figs. 2; tbls. 5. Price, 50 cts.

**Bull. 997. The Geology and Ore Deposits of the Reese River District, Lander County, Nevada.** CLYDE P. ROSS. Pp. 132; pls. 11; figs. 23. Price, $1.75.

**Bull. 1002-D. Geophysical Abstracts, October–December, 1953.** MARY C. RABBITT, S. T. VESSELOWSKY, AND OTHERS. Pp. 179–284. Price, 25 cts. *Abstract numbers 14805–15026.*

**Bull. 1006. Collected Papers on Methods of Analysis for Uranium and Thorium.** F. S. GRIMALDI, IRVING MAY, MARY H. FLETCHER, AND JANE TITCOMB. Pp. 184; pls. 8; figs. 25. Price, $1.00. *Includes 21 papers.*

**Water-Supply Paper 1205. Surface Water Supply of the United States, 1951. Part 3A. Ohio River Basin Except Cumberland and Tennessee River Basins.** Pp. 513; figs. 3. Price, $1.50.

**Water-Supply Paper 1220. Irrigation and Streamflow Depletion in Columbia River Basin above The Dalles, Oregon.** W. D. SIMONS. Pp. 126; pl. 1; fig. 1; tbl. 1. Price, 50 cts. *Evaluation of consumptive use of water based on amount of irrigation.*

**Circ. 330. The Model VI Transmission Fluorimeter for the Determination of Uranium.** CHARLES A. KINSER. Pp. 9; figs. 5.

**Circ. 331. Reconnaissance for Radioactive Deposits in Eastern Interior Alaska, 1946.** HELMUTH WEDOW, JR., P. L. KILLEEN, AND OTHERS. Pp. 36; figs. 11; tbls. 2.

**U. S. Atomic Energy Commission—Oak Ridge, Tennessee, 1953.**

**RME-47. Preliminary Report on Uranium Mineralization in the Dakota Sandstone Zuni Uplift, New Mexico.** ARTHUR MIRSKY. Pp. 21; figs. 17.

**RME-4038. Reconnaissance of the Uranium Deposits of the Lockhart Canyon—Indian Creek Area, San Juan, Utah.** GEORGE P. DIX, JR. Pp. 20; figs. 6.

**California Division of Mines—San Francisco, 1953–54.**

**Bull. 166. Geology of Lower Lake Quadrangle, California.** JAMES C. BRICE. Pp. 72; pls. 7; figs. 3. *Description of stratigraphy, petrography and structure. Economic geology includes cinnabar, chromite and asbestos deposits. Contains geologic map, 1:62,500.*

**Bull. 167. Geology of the Ortigalita Peak Quadrangle, California.** LOUIS I. BRIGGS, JR. Pp. 61; pls. 4; figs. 33. *Description of stratigraphy and structure. Contains geologic map, 1:62,500.*

**Special Rept. 36. Geology of the Palen Mountains Gypsum Deposit, Riverside County, California.** RICHARD A. HOPPIN. Pp. 25; pl. 1; figs. 32. Price, 75 cts.

**North Dakota Geological Survey Circulars, Nos. 35, 37–49.** Summary of following wells: R. R. Gibbons No. 1; Nels Magnuson No. 1; G. A. Huss No. 1; Nels Dronen No. 1; Allyn MacDiarmid No. 1; Edna L. Hild No. 1; No. 1 Duemeland; J. M. Carr No. 1; Raymond and Blanche No. 1; State No. 1; T. M. Evans-Christian Eriksen No. 1.

**Virginia Minerals and Rocks.** RICHARD V. DIETRICH. Pp. 63; figs. 42. Bull. Virginia Polytechnic Institute, Blacksburg, 1954. Price, 75 cts. *Handbook designed for secondary school students, 4-H club members, Boy Scouts and Girl Scouts.*

**Ontario Department of Mines—Toronto, 1954.**

**62nd Annual Report, Vol. LXII, Pt. 3, 1953.** Pp. 115; tbls. 19. *Contains:* Natural Gas in 1952, by R. B. Harkness, and Petroleum in 1952, by R. B. Harkness.

**62nd Annual Report, Vol. LXII, Pt. 5, 1953. Geology of the Brudenell-Raglan Area.** D. F. HEWITT. Pp. 123. *Description of general geology and structure. Economic resources include beryl, corundum and feldspar. Includes geologic map, 1: 63,360.*

**Bureau of Mineral Resources, Geology and Geophysics—Canberra, 1952–53.**

**Bull. 12. The Geology and Mineral Resources of the Brock's Creek District, Northern Territory.** C. J. SULLIVAN AND K. W. B. ITEM. Pp. 52; pls. 11; figs. 11. *Includes general geology and description of mines. Interpretation of leached outcrops indicates abundant pyrite and some sphalerite, galena and chalcopyrite.*

**Bull. 21. The Cape Range Structure, Western Australia. Pt. I, Stratigraphy and Structure.** M. A. CONDON, D. JOHNSTONE, AND W. J. PERRY. **Pt. II, Micropaleontology.** I. CRESPIN. Pp. 75; pls. 18.

**The Diamond and Gold Deposits of the Mekuru District, Cuyuni River, British Guiana.** E. R. POLLARD. Pp. 27; pl. 1; figs. 2. British Guiana Geological Survey Bull. 24, Georgetown, Demerara, 1953. Price, $1.00 (4/2).

**Notice Explicative sur la Feuille Bangassou-Ouest.** J.-L. MESTRAUD. Pp. 27. Direction des Mines et de la Géologie de l'Afrique Equatoriale Française, Brazzaville, 1953. *Brief description of geology of area. Includes geologic map, 1: 500,000.*

**Notice Explicative sur la Feuille Banyo.** P. KOCH. Pp. 47. Service des Mine du Cameroun, Yaoundé, 1953. *Brief description of geology of area. Includes geologic map, 1: 500,000.*

**Zentralblatt für Mineralogie—Stuttgart, 1953.**

**Teil I, Heft 1. Kristallographie und Mineralogie.** H. O'DANIEL. Pp. 88. *Reviews of recent articles on mineralogy.*

**Teil II, Heft 2/3. Gesteinskunde, technische Mineralogie, Geochemie und Lagerstättenkunde.** HANS SCHNEIDERHÖHN. Pp. 259–634. *Reviews of recent books and articles on geochemistry and economic geology.*

**Gesamt-Verzeichnis der Senckenberg-Schriften. Zwölfjahres-Verzeichnis für 1941–1952.** Pp. 147. Senckenbergischen Naturforschenden Gesellschaft, Frankfurt am Main, 1952. *Contains author and subject index of Senckenberg publications.*

**Rajputana University Memoirs—Udaipur, 1953.**

**No. 1. A New Theory of Sheet Movements and Continental Expansion.** K. P. RODE. Pp. 30; figs. 10.

**No. 2. The Gondwana Formations of India and the Nature of Gondwanaland.** K. P. RODE. Pp. 12; figs. 5; tbls. 2.

**Bulletin of the Hyderabad Science Association, 41st Session Science Congress Number.** Pp. 84. Hyderabad Science Assoc., Hyderabad, 1954. *Articles of general scientific interest.*

**Bull. 20, National Geographical Society of India.** Pp. 31; pls. 9; figs. 3. **Pt. I, The Drainage Patterns Observed in India and the Adjacent Countries; Pt. II, The Development of Landforms in the Himalayas.** H. L. CHIBBER. Natl. Geog. Soc. of India, Banaras, 1954.

**Council of Scientific and Industrial Research—A Review.** Pp. 142; illus. New Delhi, 1954. *Comprehensive review of personnel, research projects, results, in the 15 National Scientific laboratories established by the Government of India under the direction of the SCIR; covers also sponsored research, utilization, patents, publications, research schemes, of research laboratories of physics, chemistry, metallurgy, fuels, ceramics, food, drugs, roads, electro-chemical, leather, salt, electronics, mechanical engineering and agriculture.*

**Geological Survey of Jamaica—Kingston, 1954.**

**Bauxite Resources of Jamaica.** V. A. ZANS. Pp. 307–332; pls. 8; figs. 3. *Description of occurrence and recent developments of ferruginous bauxite.*

**Geology and Mineral Deposits of Jamaica.** V. A. ZANS. Pp. 8. *Brief synopsis and generalized geologic map, 1 inch equals 10 miles.*

**Le Rétrométamorphisme d'Amphibolites des Formations de la Lukumbi au Contact de Pegmatites Kibariennes.** JEAN VAN DE STEEN. Comité Spécial du Katanga, Sér. A, Fasc. 4, Bruxelles, 1954. Pp. 86; pls. 43; figs. 10.

**Memórias e Notícias, No. 35.** Pp. 76; pls. 9; figs. 6. Alteration of granite due to contact with vein of uranous ores, Ureirica, Portugal, by J. M. C. Neiva; On the occurrence of pigeonitic dolerites in Boila, Mozambique, by M. M. de Andsade; A rhyolite of Marracuene, Mozambique, by M. M. de Andsade; Contribution to the geochemical knowledge of Portuguese cassiterites, by M. X. de Morais; Furnas-Azores, by J. C. de Morais. Universidade de Coimbra, Portugal, 1953. *Papers have short abstracts.*

**Miscelánea Almera, VII, 2a Parte.** Pp. 354; pls. 12. Régimen hidrográfico de los derrames fluviales del nudo de los Montes Universales, by V. M. Alavedra; La hidrología cárstica de los alrededores de Campanet, by N. L. Lladó y J. M. T. Casajuana; Los carbones mineralies de Cataluna, by J. C. Miralles; El río Besós, estudio monografico de hidrología fluvial, by J. M. Puchades Benito. Instituto Geologico, Barcelona, 1948.

**Bull. of the Geological Institution, University of Upsala.** Pp. 382. *Includes 13 papers about paleontology, stratigraphy, mineralogy and structural geology.*

**Annual Report of the Geological Survey Department.** Pp. 40. Geological Survey of Tanganyika, Dar es Salaam, 1953. Price, Shs. 2/50.

**Carte Géologique de la Tunisie. Notice Explicative.** G. CASTANY. Pp. 143; pls. 14; tbls. 12. Service des Mines, Tunis, 1953. *Description of stratigraphy, structure, paleogeography and orogenesis; and mineral resources.*

**Boletin de Geologia. Vol. II, No. 6.** Pp. 333–419; pls. 32. Geologia de la region de los Teques-Cua, by Raymond J. Smith. *Description of stratigraphy and structure of area.* Introduction al estudio de la geologia de Venezuela, by Clemente González de Juana. Nota geologica: yacimento de cianita en Venezuela. Ministero de Minas e Hidrocarburos, Caracas, 1952.

**Académie Serbe des Sciences—Beograd, 1953.**

**Recueil des Travaux, T. XXXIII, No. 5.** Pp. 307. *13 papers on paleontology, mineralogy and structural geology. Each paper with abstract in German, French or English.*

**Recueil des Travaux, T. XXXIV, No. 6.** Pp. 186. *7 papers on paleontologic subjects. Each paper includes abstract in German, English or French.*

# SCIENTIFIC NOTES AND NEWS

PARKER D. TRASK just recently returned from making a survey of the natural resources of Egypt on behalf of the U. S. Geological Survey and the Foreign Operations Administration. Mr. Trask is research engineer, Dept. of Engineering, Institute of Engineering Research, Berkeley, California.

G. DESSAU, formerly of the Italian Colonial Mining Service, and after World War II attached to the Italian Geographical Survey, has retired from these services and is now associate professor of mineral deposits at the University of Naples, besides being engaged in consulting work.

R. H. B. JONES, consulting geologist for Oliver Iron Mining Div., Duluth, has been appointed staff geologist for U. S. Steel's Columbia-Geneva Steel Div. with headquarters in San Francisco. Mr. Jones joined U. S. Steel in 1930 as a geologist for Oliver Iron Mine Co. at Duluth. He was promoted to chief geologist there in 1940 and became consulting geologist in 1953.

ROBERT G. REEVES, geologist with the USGS, who was in Washington, D. C., is now back in Reno, Nevada.

WARREN J. MEAD, former head of the geology department, MIT, has been retained by Wilkes-Barre, Pa., to fix the cause of surface disturbances in South Wilkes-Barre.

JOHN D. BATES has resigned from the Bureau of Reclamation in Grand Island, Nebraska, to be with the Coastal Petroleum Company in Tallahassee, Florida.

FRANK N. AYER, copper mining consultant of New York City, has been given one of the two Egleston Medal awards for 1954. This is Columbia University's highest award "for distinguished engineering achievement."

JEAN DUFRANC has resigned from the Société des Mines de Zellidja, Bou Beker, French Morocco, where he was assistant general manager, and is now employed as manager of mining research at Bureau de Recherches Géologiques et Géophysiques, Paris.

V. A. GORSKY, consulting engineer and metallurgist, has joined the geology department of the University of Natal, Durban, South Africa.

SCOTT TURNER, consulting mining engineer of New York, has been re-elected president of the American Institute of Consulting Engineers.

J. MORROW ELIAS, former geologist with USGS at Grand Junction, Colo., is with the engineering department of Anaconda Copper Mining Co., at Butte, Montana.

PAUL T. ALLSMAN, director of Region 5, Minneapolis, has been appointed director of the U. S. Bureau of Mines' Region 7, with headquarters in Knoxville, Tenn. He succeeds Dr. Hewitt Wilson, who died November 25, 1952.

GEORGE HANSON, chief geologist of the Geological Survey, Dept. of Mines and Technical Surveys, Ottawa, has been appointed Director of the Survey to succeed Dr. W. A. Bell who, after many years as Director, has been appointed Chief Geological Consultant.

MASON RANKIN, Helena (Mont.) consulting geologist, has been appointed mining geologist for the Union Pacific Railroad at Salt Lake City.

WILLIAM M. BARRET, INC., Consulting Geophysicists, announces a change of address with occupation of its new offices, laboratories and shops at Linwood Avenue and Dalzell Street, Shreveport, Louisiana.

F. BLONDEL has been elected Président de l'Académie des Sciences coloniales, and Vice-Président de la Société des Ingénieurs civils de France for 1954.

THE SOCIETY OF EXPLORATION GEOPHYSICISTS released a report by Dr. Sigmund Hammer upon the use of geophysics for 1953. The world use was 1100 full-time crews, but with slight declines in the United States and Canada. There were 941 seismic crews, 129 gravity, 19 magnetic, and 16 others. "The use of geophysics improves the chance for success of a new-field wildcat compared to random drilling by a factor of 450 percent." Explorations on the Continental shelves continued active, mostly on the Gulf of Mexico, with 102 water-borne seismic crew-months, 27 underwater gravimeter crew-months, and 3 offshore aeromagnetic crew-months. Geophysical activity in mining showed a pronounced increase.

G. M. LEES has been awarded the Sidney Powers Medal by the American Association of Petroleum Geologists.

CHARLES COOMBS HUSTON has been elected President of the Canadian Institute of Mining and Metallurgy.

THE U. S. GEOLOGICAL SURVEY celebrated its 75th Anniversary on April 21. A program sponsored by the Washington Society of Engineers in cooperation with the District of Columbia Council of Engineering and Architectural Societies was held in the auditorium of the Interior Building, James E. Fox presiding. Bernard F. Locraft introduced Dr. W. E. Wrather, the Director, who spoke on "Seventy-five Years of Scientific Investigation," reviewing the highlights of the Survey's history. Other speakers were W. H. Bradley, Chief Geologist; H. J. Duncan, Chief, Conservation Division; C. G. Paulsen, Chief Hydraulic Engineer; Gerald Fitzgerald, Chief Topographic Engineer; and R. L. Moravetz, Chief, Publications Office. Honored guests included Secretary of the Interior Douglas McKay, Assistant Secretary Felix Wormser, and W. C. Mendenhall, Director from 1931 to 1943.

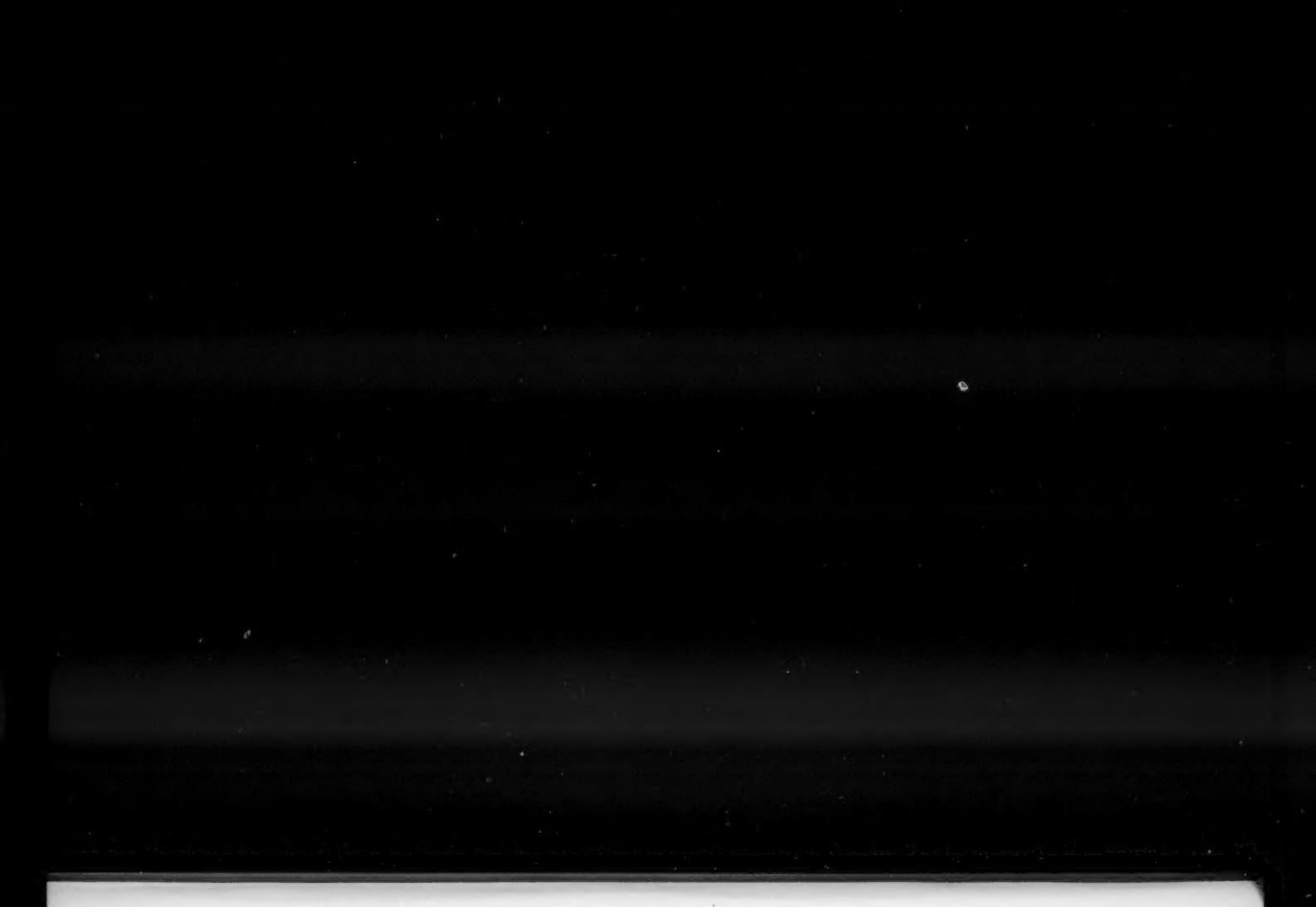
The U. S. ATOMIC ENERGY COMMISSION needs experienced geologists in its Division of Raw Materials in domestic positions in Grand Junction, Colorado. Salaries—$4,060 (GS-9), $5,940 (GS-11) and $7,040 (GS-12) depending on experience. Minimum experience is three years, some graduate work preferred. Civil Service status not required. Those interested should write to U. S. Atomic Energy Commission, Grand Junction Operations Office P. O. Box 270, Grand Junction, Colorado, Attention: Mr. E. R. Gordon, Director, Exploration Division.

J. W. BUCHTA, University of Minnesota, Minneapolis, has been appointed executive secretary of the Advisory Committee of the National Science Foundation on Government-University Relationships. The Committee, headed by Chester I. Barnard, Chairman of the National Science Board, will consider problems involving the role of the Federal Government in its support of science, both research and the training of scientists, in universities and colleges. The effects upon educational institutions of present Federal policies will be studied with the general national research objectives and the welfare of institutions in mind as a basis for recommendations of policies of the Federal Government in support of science in colleges

and universities. While serving in his new capacity, Professor Buchta will be on leave from the University of Minnesota, where he is associate dean of the College of Science, Literature and the Arts.

The Executive Committee of the INDUSTRIAL MINERALS DIVISION, AIME, has voted to extend to the Society of Economic Geologists an invitation to participate in the 1954 Fall Meeting of the Industrial Minerals Division at Whiteface Inn, Lake Placid, New York, October 5–9. Members of the SEG will be afforded the same registration privileges as the Institute members.

JACK B. GRAHAM, formerly of the U. S. Geological Survey, Washington, D. C., has joined the staff of Leggette & Brashears, Consulting Ground-Water Geologists, New York.

HAROLD L. JAMES makes the following statement: "Through a regrettable oversight on my part, certain acknowledgments were omitted from my paper "Sedimentary facies of iron-formation," published in the May issue of this journal. Specifically, grateful acknowledgment is due the Geological Survey Division of the Michigan Department of Conservation for continued support, financially and otherwise, of the U. S. Geological Survey work in northern Michigan. Also, I wish to thank the Geological Survey of Canada for the loan of thin sections of the Gunflint iron-formation of Ontario."

H. R. GAULT is returning to Lehigh University as Professor of Geology after a year's leave of absence as Executive Secretary, Division of Earth Sciences, National Research Council. He will continue his work on carbonate rocks and basic rock alteration.